DOE/EIS-0218F
February 1996

Volume 2

FINAL ENVIRONMENTAL IMPACT STATEMENT

on a

Proposed Nuclear Weapon s Nonproliferation Policy Concerning Foreign Research Reactor Spent Nuclear Fuel

Appendix B

Foreign Research Reactor Spent Nuclear Fuel Characteristics and Transportation Casks

United States Department of Energy
Assistant Secretary for Environmental Management
Washington, DC 20585

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Appendix B
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B.1 Spent Nuclear Fuel Characteristics

This section presents relevant characterization and other information on foreign research reactor spent nuclear fuel that could be managed under the proposed action. The information includes:

- Estimated amounts of spent nuclear fuel;
- A list of research reactors and foreign countries from which the spent nuclear fuel would originate;
- A description of fuel type design along with important characteristics regarding fuel design, geometry, and burnup;
- A description of the radionuclide inventories for the bounding spent nuclear fuel type; and
- An estimation of the number of foreign research reactor spent nuclear fuel shipments.

B.1.1 Estimated Amount of Spent Nuclear Fuel

The proposed action is for the U.S. Department of Energy (DOE) and Department of State to adopt a policy to manage foreign research reactor spent nuclear fuel which contains uranium enriched in the United States in a manner consistent with the goals of the U.S. nuclear weapons nonproliferation policy (see Chapter 2). The amount of spent nuclear fuel from foreign research reactors that would be managed during the policy period (1995-2005) is approximately 19.2 metric tons of heavy metal (MTHM) with a volume of approximately 110 m^3 (4,100 ft^3) representing approximately 22,700 elements[1] (see Tables B-1 and B-2). Tables B-1 and B-2 provide an estimate of the total amount of spent nuclear fuel that is currently stored or could be generated in each country by late 2005 (Matos, 1994). These tables also provide the estimated number of shipments expected from each country. The number of shipments is a key parameter in evaluating the potential risks associated with the handling and transportation of foreign research reactor spent nuclear fuel (see Section B.1.6). It should be noted that the number of spent nuclear fuel elements and the number of shipments presented for each country in this appendix are estimates based on projections of the numbers of elements to be discharged from foreign research reactors in each country listed over a 10-year period into the future. These estimates are intended to conservatively bound the total number of foreign research reactor spent nuclear fuel elements and shipments associated with the proposed policy. However, the actual distribution of elements and shipments among the listed countries might change, within the limits of the total numbers of elements and shipments listed, based on actual experience gained during the lifetime of any policy that may be established.

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1 *Various fuel forms and geometries are used in the foreign research reactors (see Section B.1.3). In order to reduce confusion, each individual spent nuclear fuel is called a spent nuclear fuel "element." An element could be an assembly, a rod, a pin, or a cluster of rods or pins.*

Table B-1 Estimated Number of Aluminum-Based Spent Nuclear Fuel Elements of U.S.-Origin Generated by Foreign Research Reactor Operators by January 2006

Country	*Estimated Number of Spent Nuclear Fuel Elements*	*Initial Mass of Uranium (kg)*[b]	*Estimated Number of Shipments*
Argentina[a]	283	71	9
Australia	975	427	9
Austria	157	191	5
Belgium	1,766	730	59
Brazil[a]	155	99	5
Canada	2,831	4,478	116
Chile[a]	58	12	2
Colombia[a]	16	2	1
Denmark	660	529	22
France	1,962	3,442	149
Germany	1,504	909	49
Greece[a]	239	113	8
Indonesia[a]	198	236	6
Iran[a]	29	6	1
Israel	192	111	6
Italy	150	43	5
Jamaica[a]	2	1	1
Japan	2,981	3,134	99
Korea (South)[a]	168	321	7
Netherlands	1,488	1,404	49
Pakistan[a]	82	16	3
Peru[a]	29	39	1
Philippines[a]	50	24	2
Portugal[a]	88	54	3
South Africa[a]	50	10	2
Spain (from Scotland)[c]	40	16	1
Sweden	1,113	1,374	37
Switzerland	159	128	5
Taiwan	127	66	4
Thailand[a]	31	5	1
Turkey[a]	69	89	2
United Kingdom	12	4	1
Uruguay[a]	19	18	1
Venezuela[a]	120	82	4
Total	**17,803**	**18,184**	**675**

[a] *Countries other than high-income economies (World Bank, 1994). These are considered to be "developing" countries.*

[b] *To derive uranium mass in pounds, multiply the amount by 2.2.*

[c] *40 spent nuclear fuel elements of Spain's JEN-1 Reactor core are stored in Dounreay, Scotland.*

In addition, in this Environmental Impact Statement (EIS), DOE is considering potential management of highly-enriched uranium (HEU) and low enriched uranium (LEU) target materials from three countries: Canada, Belgium, and Indonesia. These countries have used, and will be using, target fuels which contain U.S.-origin enriched uranium to produce molybdenum-99 (^{99}Mo), which decays to technetium-99 (^{99}Tc), a medical isotope. The amount of target materials that is expected to be brought back to the United States would contain about 556 kg of uranium in 56 to 140 shipments (see Section B.1.5 for detail).

Table B-2 Estimated Number of TRIGA Reactor Spent Nuclear Fuel Elements of U.S.-Origin Generated by Foreign Research Reactor Operators by January 2006

Country	*Estimated Number of Spent Nuclear Fuel Elements*	*Initial Mass of Uranium (kg)*[b]	*Estimated Number of Shipments*
Austria	106	20	3
Bangladesh[a]	100	49	3
Brazil[a]	75	14	3
Finland	171	33	6
Germany	358	68	12
Indonesia[a]	245	47	8
Italy	386	72	13
Japan	326	62	11
Korea (South)[a]	336	64	11
Malaysia[a]	94	47	3
Mexico[a]	186	35	6
Philippines[a]	128	79	4
Romania[a]	1,451	189	48
Slovenia[a]	393	75	13
Taiwan	144	86	5
Thailand[a]	136	35	4
Turkey[a]	79	15	2
United Kingdom	90	17	3
Zaire[a]	136	26	4
Total	4,940	1,033	162

[a] *Countries other than high-income economies (World Bank, 1994). These are identified as "developing" countries.*

[b] *To derive uranium mass in pounds, multiply the amount by 2.2.*

The information provided in Tables B-1 and B-2, with regards to the number of spent nuclear fuel elements and the amount of initial mass of uranium, is based on the following assumptions and considerations as compiled by J. Matos of Argonne National Laboratory (Matos, 1994).

B.1.1.1 Fuel Type

Under the "Offsite Fuels Policy" that was in effect during 1988, DOE accepted aluminum-based and Training, Research, Isotope, General Atomic (TRIGA) research reactor fuels[2] for disposition (DOE 1986, and 1987). The "Offsite Fuels Policy" and the current proposed policy pertain to irradiated fuels from foreign nuclear research reactors other than those involved in the conduct of research and development activities leading to demonstration of the practical value of such reactors for industrial or commercial purposes. Specifically, the "Offsite Fuels Policy" and the proposed policy apply solely to the following types of reactor fuels:

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2 *Aluminum-based fuel is aluminum-clad and has an active fuel region that consists of an alloy of uranium and aluminum or a dispersion of uranium-bearing compound (e.g., UAl_x, U_3O_8, U_3Si_2, U_3Si) in aluminum. TRIGA fuel consists of an alloy of uranium and zirconium and is clad in either aluminum, incoloy, or stainless steel.*

1. Aluminum-clad reactor fuels where the uranium-235 (^{235}U) content is equal to or greater than 20 percent, by weight, of the total uranium content (i.e., HEU fuel). The active fuel region of these fuels may be configured as uranium-aluminum alloy, uranium-oxide[3] or uranium-aluminide. Spent nuclear fuels containing significant quantities of uranium-233 (^{233}U) are excluded from receipt.

2. Aluminum-clad reactor fuels where the ^{235}U content is less than 20 percent by weight of the total uranium content (i.e., LEU fuel). The active fuel regions of these fuels may be configured as uranium-silicide, uranium-aluminide or uranium-oxide. Fuels containing significant quantities of ^{233}U are excluded from receipt.

3. Aluminum-, incoloy-, or stainless steel-clad, uranium-zirconium hydride (other than ^{233}U) TRIGA fuel types.

In addition to the aluminum-based and TRIGA fuel types discussed above, U.S.-origin enriched uranium is also used in the fuel elements of several fast reactors and other special purpose reactors, in the UO_2 rodded fuel assemblies of several thermal research reactors, and in thermal homogeneous liquid and solid fueled reactors. The enrichment of the uranium ranges from 2 percent to 93 percent. These fuels do not qualify for management under the proposed policy because they were not included in the fuel types that were eligible for return to the United States under the "Offsite Fuels Policy" that was in effect in 1988.

B.1.1.2 Data Sources and Assumptions

Information on current spent nuclear fuel inventories containing U.S.-origin enriched uranium at foreign research reactors and temporary storage facilities was obtained from several sources: (1) questionnaires sent out by DOE and returned by foreign research reactor organizations in 1993 and 1994, (2) data summarized from irradiated fuel questionnaires sent out by and returned to the International Atomic Energy Agency in 1993 and 1994, and (3) Reduced Enrichment for Research and Test Reactors (RERTR) Program information on foreign research reactor fuel inventories, operation, and fuel cycles. Additional information on reactor fuel characteristics and reactor operation was obtained from directories of nuclear research reactors published by the International Atomic Energy Agency (IAEA, 1989).

Beginning with irradiated fuel inventory data, several assumptions were made, first to normalize the data to a common starting date of January 1996, and then to estimate the number of irradiated fuel elements in reactor cores and the number of spent nuclear fuel elements that could be generated during the 10-year policy period (1995-2005). These assumptions are:

1. Most foreign research reactors will continue operation during the 10-year policy period. If a permanent shutdown date has been specified by the research reactor operator, irradiated fuel was accumulated to that date only.

2. The number of irradiated fuel elements in each reactor core was determined from available reports and publications, or estimated. The estimated number of spent nuclear fuel elements covered under the proposed policy includes the inventory within the core of each research reactor at the end of the policy period. This would account for fuel elements in the reactor core of research reactors that shut down during, or at the end of, the policy period.

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[3] *This uranium-oxide composition refers to aluminum-clad fuel plates or tubes containing dispersions of U_3O_8 in aluminum. It does not include fuels containing UO_2 pellets clad in aluminum, zircaloy, stainless steel, or other materials.*

3. Known current and planned shutdowns for prolonged periods of maintenance and refurbishment have been incorporated into the estimates.

4. Dates for conversion from HEU to LEU fuel have been estimated, and the enrichment change was incorporated into the inventory data.

5. Estimated irradiated fuel inventories have been included for reactors that are under construction and plan to begin operation before the Record of Decision date (assumed here to be December 31, 1995) of the proposed policy using U.S.-origin enriched uranium.

6. Spent nuclear fuel from previously shutdown reactors with fuel in temporary storage has been included.

B.1.1.3 Foreign Research Reactors Eligible for Inclusion in this EIS

There are 104 research and test reactors located in 41 foreign countries that possess aluminum-based and TRIGA fuels containing U.S.-origin enriched uranium. These foreign research reactors are listed in Tables B-3 through B-5. Table B-3 lists 76 reactors that possess aluminum-based fuel only. These foreign research reactors are arranged in a number of categories that depend on each reactor's LEU conversion status. Table B-4 lists 25 foreign research reactors that possess TRIGA fuel only. Table B-5 lists three foreign research reactors that were converted from HEU aluminum-based fuel to LEU TRIGA fuel and thus possess both aluminum-based and TRIGA spent nuclear fuels.

B.1.1.4 Developing Countries

For purposes of this EIS, developing countries are defined as countries having other than high-income economies, on the basis of per capita Gross Domestic Product, by the World Bank (World Bank, 1994). Two countries, Zaire and Taiwan, were not listed in the World Bank report. Zaire is considered here to have a low-income economy; and Taiwan, with an estimated per capita Gross Domestic Product of $10,900 (1994), is considered to have a high-income economy. The countries shown below qualify as developing countries according to this criterion:

List of Developing Countries

Low Income Economies	*Lower Middle Income Economies*		*Upper Middle Income Economies*	
Bangladesh	Chile	Romania	Argentina	Slovenia
Indonesia	Colombia	Thailand	Brazil	South Africa
Pakistan	Iran	Turkey	Greece	South Korea
Zaire	Jamaica		Malaysia	Uruguay
	Peru		Mexico	Venezuela
	Philippines		Portugal	

B.1.2 General Characteristics of Nuclear Fuels and Spent Nuclear Fuel

Nuclear fuels consist of fissile materials that produce a net increase in neutrons when they absorb neutrons, and fertile materials that produce fissile material when they absorb neutrons. The principal fissile materials are ^{235}U, Plutonium-239 (^{239}Pu), and ^{233}U (Plutonium-241 or ^{241}Pu is also of some importance). The principal fertile materials are uranium-238 (^{238}U) and Thorium-232 (^{232}Th) (Plutonium-240 or ^{240}Pu and uranium-234 or ^{234}U also play roles as fertile materials). The only fissile

Table B-3 Foreign Research and Test Reactors that Possess Only Aluminum-Based Fuel Containing HEU and LEU of U.S.-Origin

	Reactor	*Country*	*Power, MW*	*Fuel Geometry*	*Initial Enrichments[a] Wt-% ^{235}U, U.S. Origin*			*Comment (see Note)*
					Enr.1	*Enr.2*	*Enr.3*	
HEU Reactors Fully- or Partially-Converted to LEU Fuel								
1	RA-3	Argentina	3	Plates	90	-	-	(1)
2	ASTRA	Austria	10	Plates	93	45	20	
3	IEA-R1	Brazil	2	Plates	93	-	20	
4	NRU	Canada	125	Pin Cluster	93	-	20	
5	DR-3	Denmark	10	Tubes	93	85	20	
6	OSIRIS	France	70	Plates	-	-	20	
7	FRG-1	Germany	5	Plates	93	-	20	
8	NRCRR	Iran	5	Plates	93	-	-	(2)
9	JMTR	Japan	50	Plates	93	45	20	
10	PARR	Pakistan	5	Plates	92	-	-	(2)
11	R2	Sweden	50	Plates	93	-	20	
HEU Reactors that Have Ordered LEU Fuel Elements for Conversion								
12	GRR-1	Greece	5	Plates	93	-	20	(3)
13	HOR	Netherlands	2	Plates	93	-	20	(3)
14	TR-2	Turkey	5	Plates	93	-	20	(3)
HEU Reactors that Can Be Converted to LEU Fuel								
15	RA-6	Argentina	0.5	Plates	90	-	-	
16	HIFAR	Australia	10	Tubes	80	60	20	(3)
17	SAR-GRAZ	Austria	0.01	Plates	90	-	20	
18	MNR	Canada	2	Plates	93	-	20	
19	Slowpoke - Alberta	Canada	0.02	Pin Bundle	93	-	-	
20	Slowpoke - Halifax	Canada	0.02	Pin Bundle	93	-	-	
21	Slowpoke - Montreal	Canada	0.02	Pin Bundle	93	-	-	
22	Slowpoke - Saskatchewan	Canada	0.02	Pin Bundle	93	-	-	
23	Slowpoke - Toronto	Canada	0.02	Pin Bundle	93	-	-	
24	LA REINA	Chile	5	Plates	80	-	-	
25	IAN-R1	Colombia	0.03	Plates	90	-	-	
26	EOLE	France	0.01	Plates	93	-	-	
27	MINERVE	France	0.003	Plates	93	-	-	
28	SCARABEE	France	20	Plates	93	-	-	
29	Strasbourg - Cronenbourg	France	0.1	Plates	90	-	-	
30	Ulyssee - Saclay	France	0.1	Plates	90	-	-	
31	BER-II	Germany	10	Plates	93	-	20	(3)
32	FRJ-2	Germany	23	Tubes	80	-	20	(3)
33	FRM	Germany	4	Plates	93	45	-	
34	IRR-1	Israel	5	Plates	93	-	20	(3)
35	Slowpoke	Jamaica	0.02	Pin Bundle	93	-	-	
36	JMTRC	Japan	0	Plates	93	45	-	
37	JRR-4	Japan	3.5	Plates	93	-	20	(3)
38	KUCA	Japan	0	Plates	93	45	-	
39	KUR	Japan	5	Plates	93	-	20	(3)
40	UTR Kinki	Japan	0	Plates	90	-	-	
41	HFR Petten	Netherlands	45	Plates	93	-	20	(3)
42	LFR	Netherlands	0.03	Plates	93	-	-	
43	RPI	Portugal	1	Plates	93	-	20	
44	SAFARI	S. Africa	20	Plates	93	-	-	(4)

	Reactor	Country	Power, MW	Fuel Geometry	Initial Enrichments[a] Wt-% ^{235}U, U.S. Origin			Comment (see Note)
					Enr.1	Enr.2	Enr.3	
45	R2-0	Sweden	1	Plates	90	-	-	
46	ZPRL	Taiwan	0.01	Plates	93	-	20	
HEU Operating Reactors that Cannot be Converted with Current Technology								
47	BR-2	Belgium	60	Tubes	90-93	-	-	
48	ORPHEE	France	14	Plates	93	-	-	
49	RHF	France	57	Involute Plates	93	-	-	
HEU Operating Reactors Announced to be Shutdown								
50	SILOE	France	35	Plates	93	45	20	
51	SILOETTE	France	0.1	Plates	93	-	-	
52	FMRB	Germany	1	Plates	93	-	-	
53	FRG-2	Germany	15	Plates	90 - 93	-	20	
54	JRR-2	Japan	10	Plates	93	45	-	
55	UTR 300	U. K.	0.3	Plates	90	-	-	
Shutdown Reactors Possessing HEU Fuel								
56	MOATA	Australia	-	Plates	90	-	-	
57	BR-02	Belgium	-	Tubes	90	-	-	
58	NRX	Canada	-	Pin Cluster	93	-	-	
59	PTR	Canada	-	Plates	93	-	-	
60	Slowpoke - Kanata	Canada	-	Pin Bundle	93	-	-	
61	MELUSINE	France	-	Plates	93	-	-	
62	GALILEO	Italy	-	Plates	89	-	-	
63	ISPRA-1	Italy	-	Plates	90	-	-	
64	RANA	Italy	-	Plates	90	-	20	
65	JEN-1	Spain	-	Plates	79	-	20	(5)
66	SAPHIR	Switzerland	-	Plates	93	45	20	
LEU Operating Reactors Possessing Only LEU Fuel								
67	RA-0	Argentina	0.01	Plates	-	-	20	
68	Argonauta	Brazil	0.2	Plates	-	-	20	
69	RSG-GAS30	Indonesia	30	Plates	-	-	20	
70	JRR-3M	Japan	20	Plates	-	-	20	
71	TTR-1	Japan	0.1	Plates	-	-	20	
72	RP-10	Peru	10	Plates	-	-	20	
73	KMRR	S. Korea	30	Pin Cluster	-	-	20	(6)
LEU Shutdown Reactors Possessing Only LEU Fuel								
74	THAR	Taiwan	-	Plates	-	-	20	
75	RU-1	Uruguay	-	Plates	-	-	20	
76	RV-1	Venezuela	-	Plates	-	-	20	

[a] *Initial enrichments, in weight-% ^{235}U, of the fuels possessed or anticipated to be possessed by each reactor. Only fuels containing uranium of U.S.-origin are included.*

Note:

(1) *Converted to LEU fuel of Soviet origin.*

(2) *Converted to LEU fuel of Chinese origin.*

(3) *Use of fuel containing LEU of U.S.-origin is anticipated to begin before 2001.*

(4) *Currently uses HEU of South African origin.*

(5) *JEN-1 fuel is currently being stored in Dounreay, Scotland.*

(6) *The KMRR reactor in South Korea began operation using LEU aluminum-based fuel in January 1995.*

Table B-4 Foreign Research and Test Reactors that Possess Only TRIGA Fuel Containing HEU and LEU of U.S.-Origin

	Reactor	Country	Power, MW	Fuel Geometry	Initial Enrichments[a] Wt-% ^{235}U, U.S. Origin		
					Enr.1	Enr.2	Enr.3
Reactors Possessing HEU Fuel							
1	Vienna	Austria	0.25	Rods	70	-	20
2	Salazar	Mexico	1	Rods	70	-	20
3	SSR	Romania	14	Rods	93	-	20
4	Ljubljana	Slovenia	0.25	Rods	70	-	20
5	Seoul #2	S. Korea	2	Rods	70	-	20
Reactors Possessing LEU Fuel							
6	Dhaka	Bangladesh	3	Rods	-	-	20
7	Belo Horiz.	Brazil	-	Rods	-	-	20
8	Helsinki	Finland	0.25	Rods	-	-	20
9	Hannover	Germany	-	Rods	-	-	20
10	Heidelberg	Germany	0.25	Rods	-	-	20
11	Mainz	Germany	0.1	Rods	-	-	20
12	Bandung	Indonesia	1	Rods	-	-	20
13	Yogyakarta	Indonesia	0.1	Rods	-	-	20
14	Pavia	Italy	0.25	Rods	-	-	20
15	Rome	Italy	1	Rods	-	-	20
16	Mushashi Inst	Japan	0.1	Rods	-	-	20
17	NSRR-Tokai	Japan	0.3	Rods	-	-	20
18	Rikkyo U.	Japan	0.1	Rods	-	-	20
19	Kuala Lumpur	Malaysia	1	Rods	-	-	20
20	ACPR	Romania	0.5	Rods	-	-	20
21	Seoul #1	S. Korea	0.25	Rods	-	-	20
22	Istanbul	Turkey	0.25	Rods	-	-	20
23	Imp Chem Ind.	U. K.	0.25	Rods	-	-	20
24	TRICO II	Zaire	1	Rods	-	-	20
Shutdown Reactors							
25	TRICO I	Zaire	-	Rods	-	-	20

[a] *Initial enrichments, in weight-% ^{235}U, of the fuels possessed by each reactor. Only fuels containing uranium of U.S.-origin are included.*

Table B-5 Foreign Research and Test Reactors that Possess Both Aluminum-Based and TRIGA Fuel Containing HEU and LEU of U.S.-Origin.

	Reactor	Country	Power, MW	Fuel Geometry	Initial Enrichments[a] Wt-% ^{235}U, U.S. Origin		
					Enr.1	Enr.2	Enr.3
1	PRR-1	Philippines	3	TRIGA Rods	-	-	20
			-	Plates	93	-	20
2	THOR	Taiwan	1	TRIGA Rods	-	-	20
			-	Plates	93	-	
3	TRR-1	Thailand	2	TRIGA Rods	-	-	20
			-	Plates	90	-	-

[a] *Initial enrichments, in weight-% ^{235}U, of the fuels possessed by each reactor. Only fuels containing uranium of U.S.-origin are included.*

Note:

All three of these reactors have been converted from plate-type, aluminum-based HEU fuel to TRIGA LEU fuel. The PRR-1 reactor in the Philippines possesses both HEU and LEU cores of plate-type aluminum-based fuel elements.

material that occurs in nature in a significant quantity is ^{235}U. Natural uranium consists of 0.711 weight percent (w/o) ^{235}U, 99.283 w/o ^{238}U; and 0.0055 w/o ^{234}U as a negligible trace constituent. Uranium-235 is the only fissile material used in foreign research reactors.

In a research reactor, the fuel matrix typically consists of enriched uranium metal in an alloy of aluminum or zirconium hydride. The enriched uranium may contain up to 93 weight percent ^{235}U. The fuel matrix form is either plates (flat or curved), tubes made of three curved plates, or pellets combined into rods. The cladding is the encapsulation (typically aluminum or stainless steel) that surrounds the fuel for confinement and protection. The structural part of a fuel element holds fuel plates or tubes in the proper configuration and directs coolant flow (light or heavy water) over the fuel. Structural parts are usually aluminum. The fuel rods do not require additional structural parts. The size of a fuel element ranges from approximately 1 kg (2.2 lb) to more than 100 kg (220 lb), and lengths range from 76 to 300 cm (2.5 to 9 ft).

As the fuel in a reactor is irradiated, it undergoes nuclear transmutations that cause its composition to change. In the reactor, the fissionable materials in the fuel undergo a process called "fission reaction." Fission reaction occurs when an atom of ^{235}U interacts with a free neutron causing the ^{235}U atom to split into two lighter nuclei which are referred to as "fission products." The fission reaction also results in the release of heat and additional free neutrons that are available to sustain the fission reaction or to maintain criticality. In addition to fission products, heavier elements such as plutonium and other isotopes of uranium are formed when uranium in the fuel absorbs free neutrons rather than undergoing the fission process. The changes in composition of the fuel bring about changes in the fission reaction rate of the fuel. As the reactor operation continues, the fission reaction rate decreases and eventually the reactor will no longer remain critical unless some spent nuclear fuels are replaced with fresh fuels. The discharged fuel is called "spent nuclear fuel." The extent of change in the composition of the fuel is expressed in terms of "burnup," in either percent (atom percent) of fissile material consumed, or the number of megawatt days of heat released per element (or per metric ton of uranium).

When initially discharged from the reactor, spent nuclear fuel is highly radioactive and generates a significant amount of heat. Therefore, the spent nuclear fuel must be stored in a wet pool that provides both shielding and cooling environments. The cooling is required in order to prevent the spent nuclear fuel from being damaged by the heat that fission products generate, and the shielding is needed to protect the workers who handle the fuel.

The quantity of radioactive material in spent nuclear fuel, and the resulting heat generation, decreases over time because of decay of fission products in the spent nuclear fuel. Radioactive decay refers to a process whereby the radioactive elements undergo nuclear transformations that ultimately convert them to stable (nonradioactive) elements. Many fission products formed during reactor operation have short half-lives (the time required for a quantity of radioactive material to decrease to one-half of its original amount) and others remain radioactive for tens to thousands of years. The high initial quantities of fission products in the spent nuclear fuel put the greatest requirements on providing shielding and cooling during the first few months after the spent nuclear fuel is discharged from the reactor. The rapid decay of short half-lived radioactive material leads to reduction of the amount of radioactive material in the spent nuclear fuel over time. This, in turn, reduces the need for continued storage of the spent nuclear fuel in a wet pool. After about 1 year, the heat generation rate in a spent nuclear fuel element decreases to about one percent of the level present at the time of its discharge from the reactor, and this heat generation rate would not damage the spent nuclear fuel if it is stored in a "dry" cask in preparation for transportation and dry storage.

B.1.3 Foreign Research Reactor Spent Nuclear Fuel Designs

Foreign research reactors use a number of different fuel designs. These designs can be organized into five categories: (1) plate-type design, (2) concentric tube-type design, (3) pin-type design, (4) special-type design, and (5) rod-type design. The first four designs are aluminum-based fuel while the fifth is a TRIGA type. The first two fuel types (plate-and tube-type fuels) are known as material test reactor (MTR) fuels. The following summarizes specific characteristics of the different types of fuel named above.

B.1.3.1 Plate-Type Design

This type of fuel design is used in the majority of foreign research reactors. The thermal power of these reactors ranges from 1 MW to 50 MW. Figures B-1 and B-2 show typical fuel elements using this type of fuel design. The number of fuel plates in an element varies between 6 and 23, and the initial ^{235}U content[a] varies between 37 g (1.3 oz) and 420 g (14.8 oz) per element. Similarly, the average burnup of a discharged spent nuclear fuel varies between 15 and 76 percent (^{235}U atom percent). The uranium enrichment in this type of fuel varies from just below 20 to 93 percent.

The following provides additional information on a typical plate-type spent nuclear fuel element which was used in a 50 MW foreign research reactor, as shown in Figure B-2.

The fuel element is made of an alloy of 23 percent by weight of 93 percent enriched uranium in aluminum with a thin (0.38 mm) aluminum cladding. Each fuel element contains 19 fuel plates. The nominal dimensions and weights of each fuel plate and the fuel element are:

	Fuel Plate	*Element*	*Element (cut)*
Dimensions (mm):			
Length	778	1,200	800
Width	70.8	77.0	77.0
Height	1.27[a]	77.0	77.0
Weight (g):			
^{235}U	15	285	285
Total	202	--	5,500
Burnup:			
^{235}U (g)	~3	60	60

[a] *Thickness*

The cut element reflects that portion of the fuel element that contains fuel material. The aluminum nose cone and the aluminum top section of the fuel element are cut to reduce the size of the spent nuclear fuel prior to shipment. This action is usually performed at the foreign research reactor site if the site is equipped to do so. The cutting is necessary to pack more cut elements in a transportation cask, and also since some casks cannot accommodate the whole element length.

B.1.3.2 Concentric Tube Design

This type of fuel design is used in four foreign research reactors: Australian (HIFAR), Belgian (BR-2), Japanese (JRR-2) and Danish (DR-3). The Belgian reactor is a 125 MW reactor, and the other three are each 10 MW. Figure B-3 shows a typical fuel element using concentric tube (tubular) fuel type. The number of fuel tubes in an element varies between 4 and 6, and the initial ^{235}U content varies between

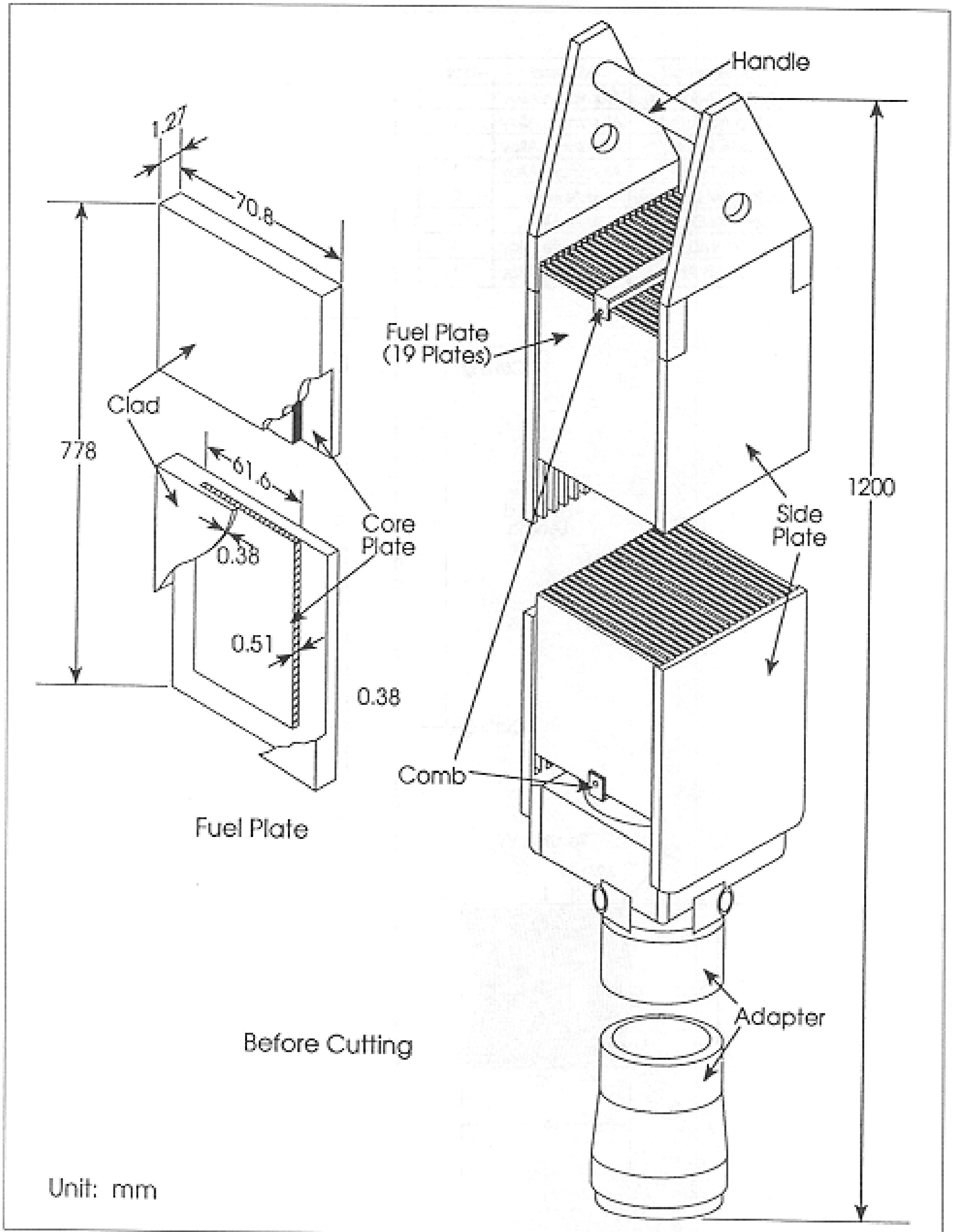
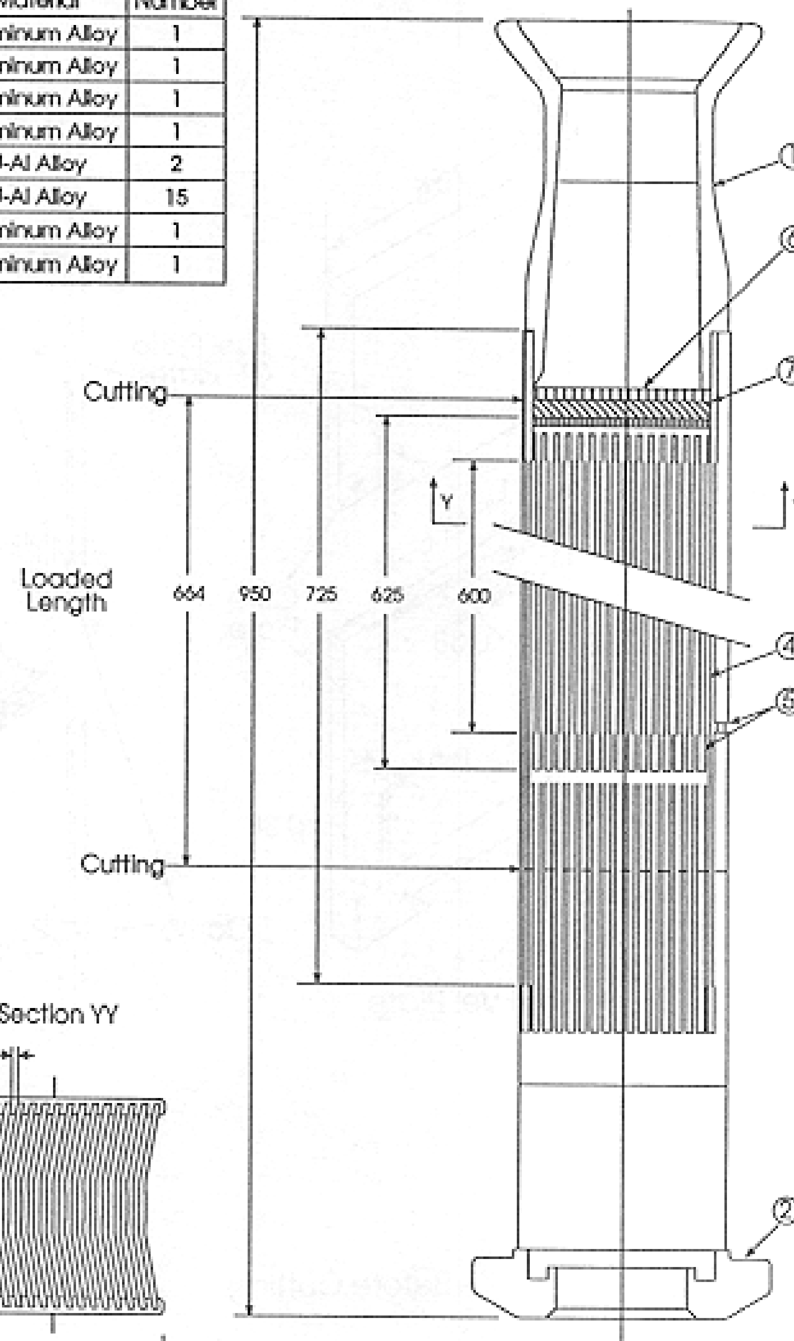


Figure B-1 Typical (Boxed-Type/Flat Plate) Aluminum-Based Fuel Element Schematic

Part No.	Name of Part	Material	Number
1	Bottom Adapter	Aluminum Alloy	1
2	Top Adapter	Aluminum Alloy	1
3R	Side Plate	Aluminum Alloy	1
3L	Side Plate	Aluminum Alloy	1
4	Outer Fuel Element	U-Al Alloy	2
5	Inner Fuel Element	U-Al Alloy	15
6	Comb	Aluminum Alloy	1
7	Comb Pin	Aluminum Alloy	1

Unit = mm



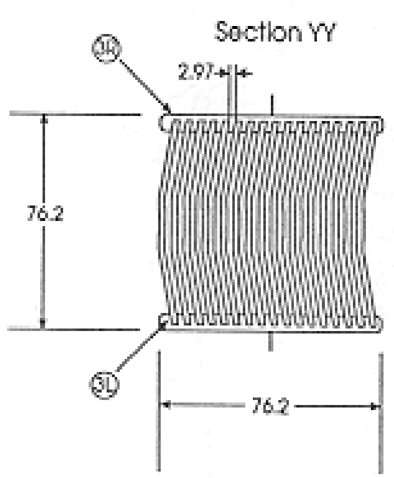


Figure B-2 Typical (Boxed-Type/Curved Plate) Aluminum-Based Fuel Element Schematic

Part No.	Name of Part	Material	Number
1	Bottom Adapter	Aluminum Alloy	1
2	Top Adapter	Aluminum Alloy	1
3	Outer Cylinder	Aluminum Alloy	1
4	Plate	Aluminum Alloy	3
5	Fuel Plate	————	5x3
6	Inner Layer Plate	Aluminum Alloy	3
7	Top Capsule Guide	Aluminum Alloy	1
8	Comb Plate	Aluminum Alloy	3
9	Capsule Guide	Aluminum Alloy	1
10	Comb	Aluminum Alloy	3

Unit = mm

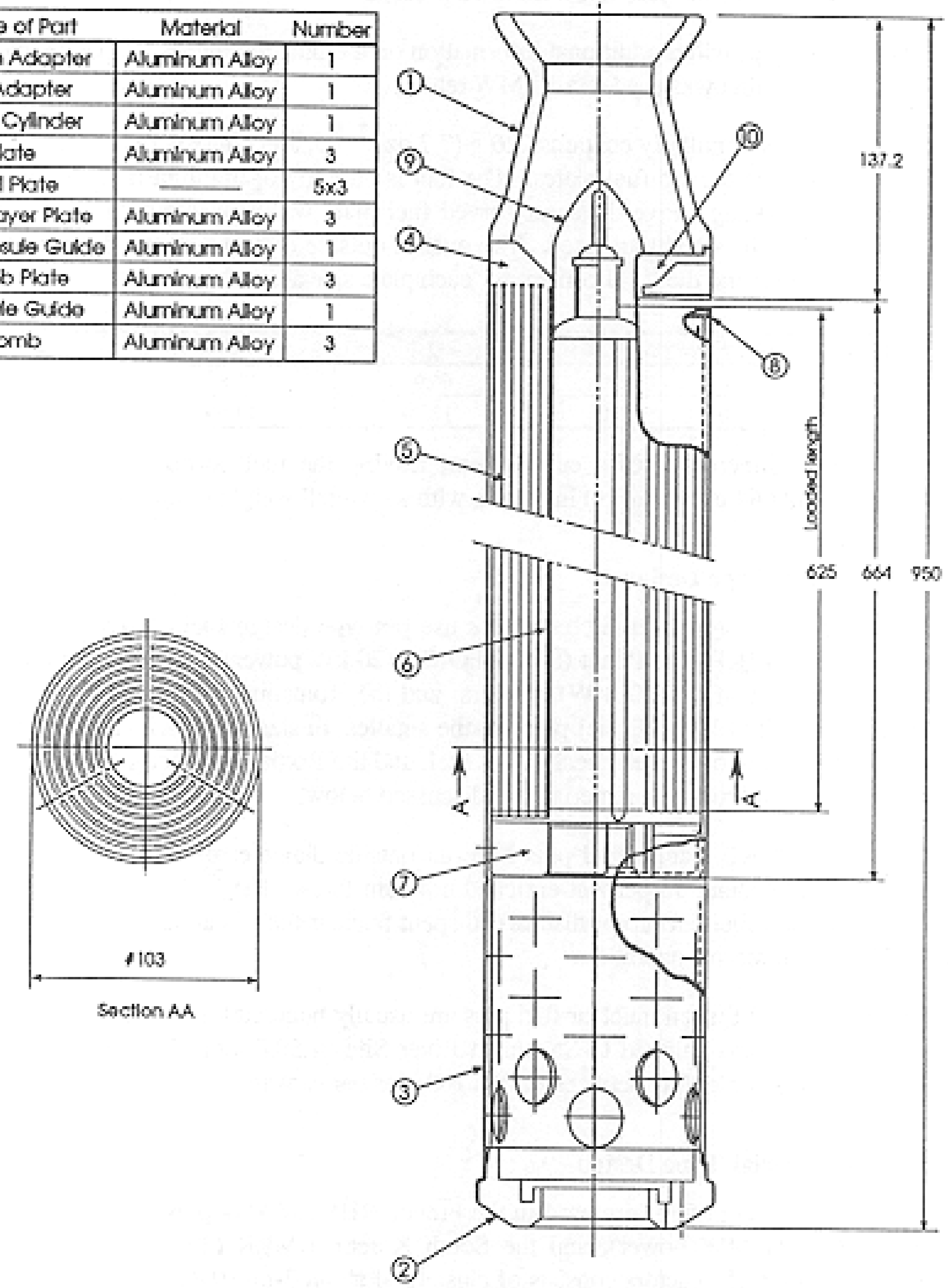


Figure B-3 Typical (Tube-Type) Aluminum-Based Fuel Element Schematic

150 g (5.3 oz) and 400 g (14.6 oz) per element. The average burnup of discharged spent nuclear fuels from these reactors ranges between 47 and 55 percent (^{235}U atom percent). The uranium enrichment used in this fuel varies from just below 20 to 93 percent.

The following provides additional information on a typical tubular type spent nuclear fuel element (shown in Figure B-3) that was used in a 10 MW reactor.

This fuel element initially contains 220 g (7.7 oz) ^{235}U, and consists of 5 concentric fuel tubes. Each tube is made of three curved fuel plates. The fuel is an alloy of uranium in aluminum with a thin (0.38 mm) aluminum cladding. Five different curved fuel plate width sizes with 1.27 mm (0.05 in) thickness and 625 mm (24.6 in) height are used. The overall outside diameter of the outermost tube is 103 mm (4 in). The plate width and the ^{235}U content for each plate size are:

Plate Number	*1*	*2*	*3*	*4*	*5*
Width (mm)	57.9	66.9	75.8	84.8	93.7
^{235}U (g)	10.70	12.70	14.60	16.60	18.60

The overall dimensions of a cut element, leaving the fuel portion intact, are 103 mm (4 in) outside diameter and 664 mm (25.4 in) in length, with an overall weight of approximately 6,000 g (13.2 lbs).

B.1.3.3 Pin-Type Design

Three types of foreign research reactors use pin-type design fuel. They are: the Canadian Safe LOW POwer critical [K] Experiment (SLOWPOKE) (20 kW power); the Canadian NRU (125 MW power) and South Korean KMRR (30 MW) reactors; and the Romanian TRIGA (14 MW) reactors. Among these reactors, the SLOWPOKE fuel pins are the smallest in size and uranium content. The NRU and KMRR reactor fuels are considered special type fuel, and the Romanian reactor fuels are TRIGA or rod-type fuel. Special-type and rod-type materials are discussed below.

The SLOWPOKE reactor fuel pins have an outside diameter of 4.73 mm (0.2 in), a length of 220 mm (8.7 in), and contain 93 percent enriched uranium fuels. The ^{235}U content of each pin is 2.8 g (0.1 oz). The maximum fuel burnup of discharged spent nuclear fuels is about 2 percent (^{235}U atom percent) in 10 to 20 years of reactor operation.

The SLOWPOKE spent nuclear fuel pins are usually bundled together in 10 to 15 pins per bundle. In the past, this fuel was shipped to Savannah River Site in 50.8-mm (2-in) outside diameter, 2.9-m- (9.6-ft-) long canisters containing between 150 to 160 pins per canister.

B.1.3.4 Special-Type Design

Special-type design fuels are used in the French RHF (57 MW power), Canadian NRU (125 MW power) and NRX (24 MW power), and the South Korean KMRR (30 MW) reactors. The fuel type in the Canadian research reactors consists of clusters of about 3-m- (9.84-ft-) long uranium aluminum alloy fuel pins clad in aluminum. The initial ^{235}U content of each fuel cluster varies between 491 g (17.3 oz) and 545 g (19.2 oz). The current operating reactor (NRU) uses a fuel element that consists of a cluster of 12 long pins containing 491 g (17.3 oz) of ^{235}U per cluster. Each fuel pin has an overall length of 296 cm (116.5 in), and the fuel portion is 274.3 cm (107.9 in) long. The fuel cluster including the flow tube is cut to a length of 292.6 cm (115.2 in) before shipment. The average burnup of discharged spent nuclear fuels from an NRU reactor is about 76 percent (^{235}U atom percent). Figure B-4 shows a 12-pin cluster NRU fuel element. The fuel in the South Korean research reactor consists of two types of fuel clusters; one is

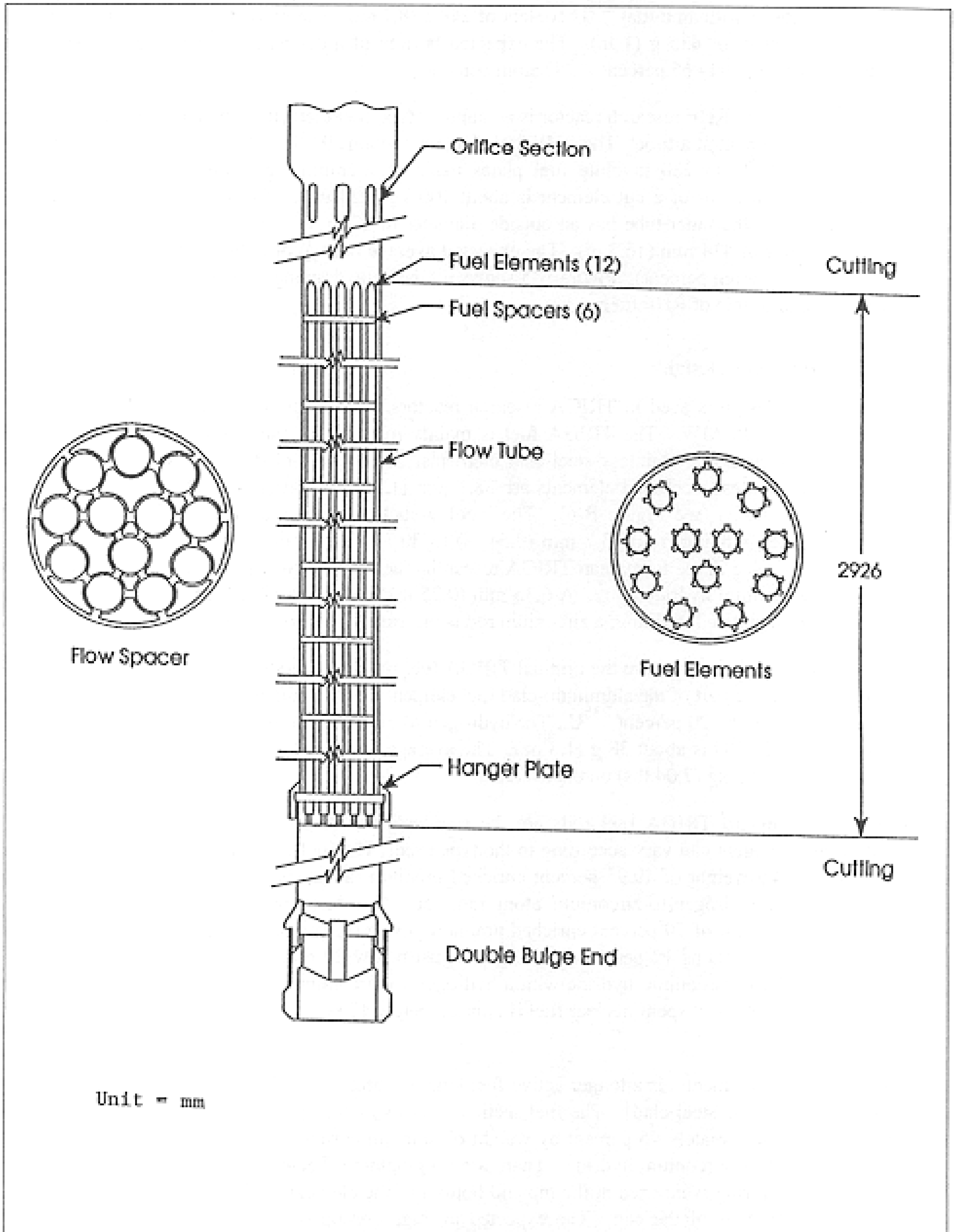


Figure B-4 Typical NRU Type (Aluminum-Based) Fuel Element Schematic

18 pins per cluster with an initial ^{235}U content of 248 g (8.7 oz). The second is 36 pins per cluster with an initial ^{235}U content of 435 g (1 lb). The expected burnup of a discharged spent nuclear fuel from this reactor is approximately 65 percent (^{235}U atom percent).

The fuel used in the RHF research reactor is an annular-type fuel element. The RHF research reactor uses only one fuel element at a time. The RHF fuel element contains 9.2 kg (20.3 lbs) of uranium, enriched to 93 percent, in ^{235}U in 280 involute fuel plates made of uranium aluminum alloy (UAl_3-Al) clad in aluminum. The weight of a cut element is about 100 kg (220 lbs). The fuel is in the annulus of two aluminum tubes: the inner tube has an outside diameter of 274 mm (10.8 in), and the outer tube has an outside diameter of 414 mm (16.3 in). The expected average burnup of a discharged spent nuclear fuel is 36 percent (^{235}U atom percent). Figure B-5 shows a schematic drawing of a configuration of annular fuel element similar to that of RHF fuels.

B.1.3.5 Rod-Type Design

This fuel type design is used in TRIGA research reactors. These research reactors have power ranging from 100 kW to 14 MW. The TRIGA fuel is mainly made up of three basic types of fuel elements: aluminum-clad elements, stainless steel-clad elements, and incoloy-clad elements. All aluminum-clad elements and stainless steel-clad elements are 38.1-mm (1.5-in) diameter by 762-mm- (30-in-) long rods including end fittings (see Figure B-6). The incoloy-clad elements are of the same length, but with a smaller diameter, ranging from 13.7 mm (0.54 in) to 30.7 mm (1.2 in). The 13.7-mm (0.54-in) fuel is currently being used in the Romanian TRIGA research reactor. The fuel is a solid, homogeneous mixture of uranium zirconium hydride alloy. A 6.35-mm (0.25-in) hole is drilled through the center of the active fuel section to facilitate hydriding; a zirconium rod is inserted in this hole after hydriding is complete.

The aluminum-clad elements are the original TRIGA fuel rods that are still in use at some foreign research reactors. The active part of the aluminum-clad fuel element contains about 8 percent by weight of uranium enriched to just below 20 percent ^{235}U. The hydrogen-to-zirconium atom ratio is approximately 1.0. The initial loading of ^{235}U is about 38 g (1.3 oz). The average burnup of this type of fuel is about 8 percent. Each rod weighs 3.2 kg (7.04 lbs) on the average.

The current standard TRIGA fuel rods are the stainless steel-clad elements. The fuel content of the stainless steel element can vary according to the type used. The fuel content of a standard rod consists of 8 to 9 percent by weight of 19.95 percent enriched uranium [about 39 g (1.4 oz) of ^{235}U] in zirconium hydride, with a hydrogen-to-zirconium atom ratio of 1.7. Another type, known as FLIP, contains 8.5 percent by weight of 70 percent enriched uranium [137 g (4.8 oz) of ^{235}U]. The annular core pulsed reactor fuel type contains 12 percent by weight of just below 20 percent enriched uranium [about 54 g (1.9 oz) of ^{235}U] in zirconium hydride with a hydrogen-to-zirconium ratio of 1.7. The expected average burnup of the discharged spent nuclear fuel is approximately 15 percent. Each rod weighs 3.6 kg (7.9 lbs) on the average.

The incoloy-clad element has a longer active fuel length [558.8 mm (22 in) compared to 381 mm (15 in) for standard stainless steel-clad]. The fuel section consists of four pellets, each 139.7-mm (5.5-in) long, and contains approximately 45 percent by weight of uranium enriched to 20 percent [approximately 54 g (1.9 oz) of ^{235}U] in zirconium hydride. There are no graphite reflectors within this element. Instead, a 76.2-mm (3-in) spring is inserted at the top and bottom of the element, and stainless steel end fixtures are attached to both ends of the can. The expected average burnup of this fuel in the Romanian TRIGA reactor is about 52 percent.

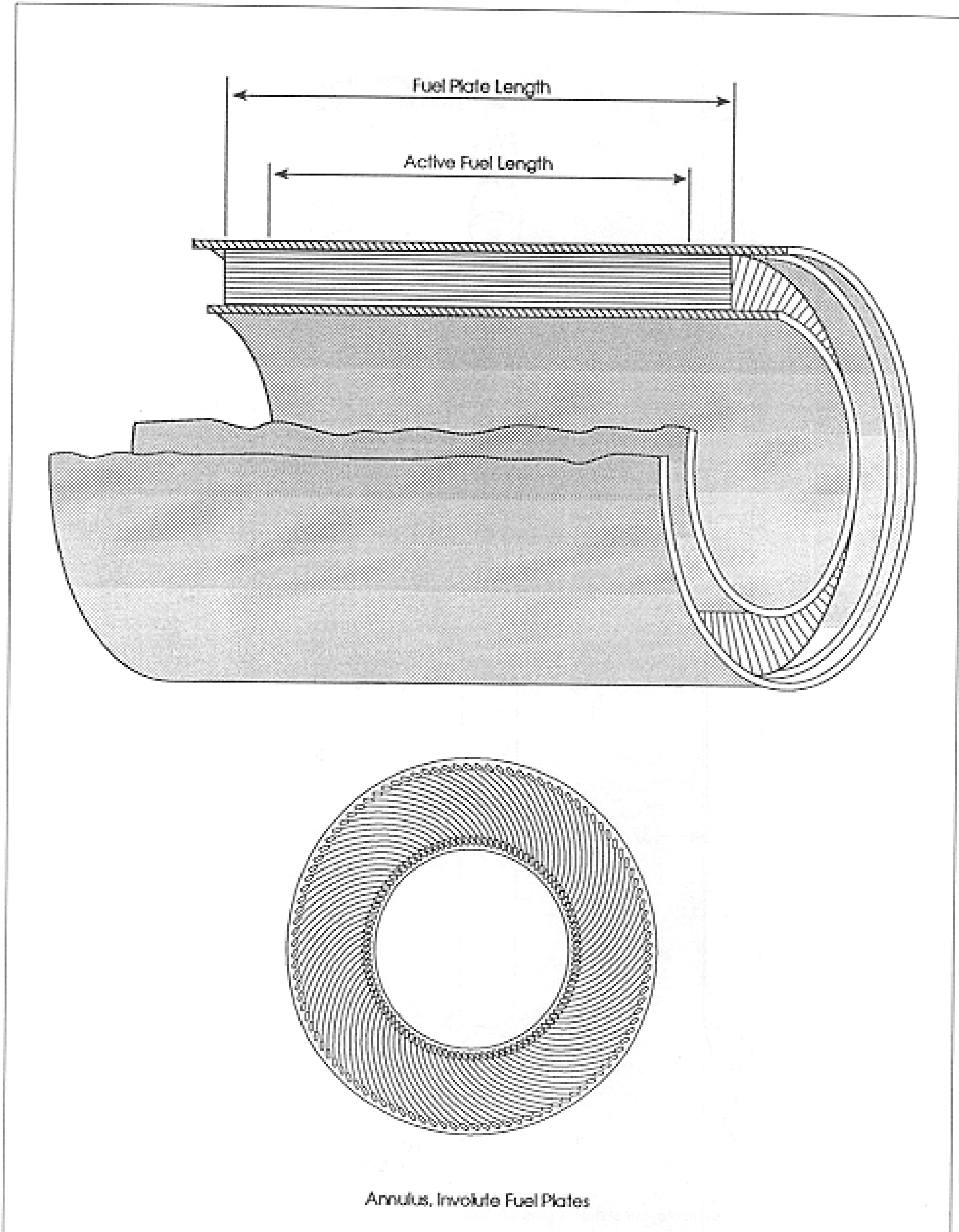
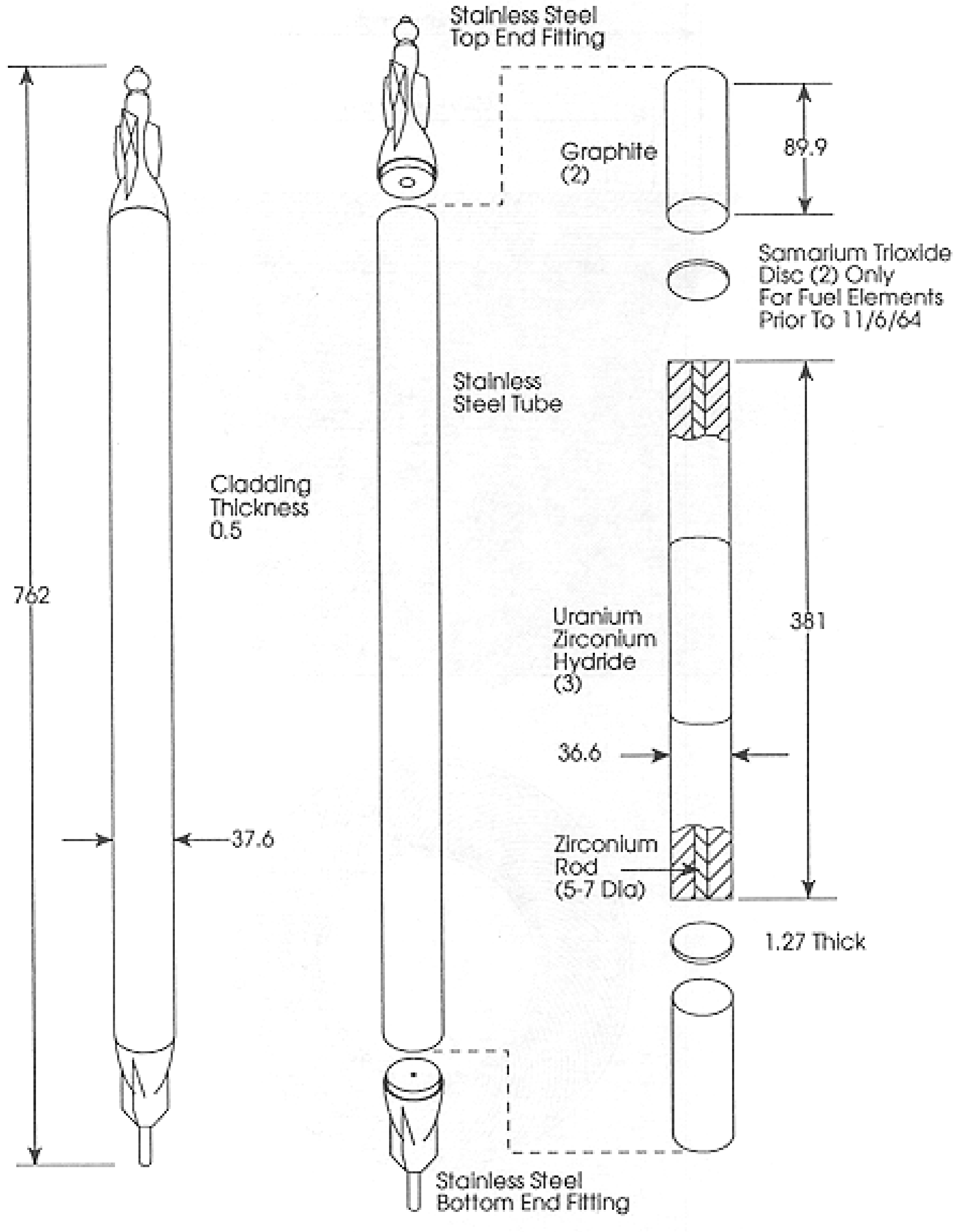


Figure B-5 Typical Annular-Type (Aluminum-Based) Fuel Element Schematic



(Fuel could have aluminum, incoloy, or stainless steel cladding) Unit = mm

Figure B-6 Typical TRIGA Fuel Element Schematic

B.1.4 Description of the Bounding Radionuclide Inventory

The spent nuclear fuel radionuclide concentration (or inventory) is directly related to the initial mass of fuel (fissile and fertile), the level of burnup, and the cooling period (or decay period) following fuel discharge from the reactor. The fuel burnup is a function of the fuel position inside the reactor core resulting in some fuels burning more than others. A well-designed fuel management program, however, reduces burnup variations among fuel elements. The radionuclide generation in an irradiated fuel is a function of reactor power level and the duration of irradiation process. Research reactors have irregular irradiation profiles, and are typically operated at various power levels. For the calculation of the radionuclide inventory, each fuel element was assumed to have been burnt uniformly and continuously at full reactor power before its discharge. These assumptions maximize the radionuclide inventories of the spent nuclear fuel. As stated earlier, the cooling or decay time after fuel discharge from the reactor determines the amount of radionuclides that remains in the spent nuclear fuel.

Based on the discussion in Section B.1.3, the foreign research reactor spent nuclear fuels were grouped into three classes and four fuel categories for the determination of bounding radionuclide inventories. This subdivision was created in order to provide a better representation of potential radionuclide inventories associated with each type of fuel. This subdivision also provides a means for identifying the type of transportation casks needed, and estimating the number of spent nuclear fuel shipments. The radionuclide inventories per shipment are needed as input to marine and ground transportation and cask handling impact analyses.

The selected fuel types for the determination of bounding radionuclide inventories are:

1. ***Special.*** These are aluminum-based fuels that are neither TRIGA nor MTR. Special fuels are also different in size and geometry.

   1a. *Single Element Reactors.* Spent nuclear fuel from research reactors that operate with one element (e.g., RHF of France). These spent nuclear fuels contain several kg of ^{235}U and require special shipping baskets, casks, and transportation analyses.

   1b. *NRU Type Spent Nuclear Fuel.* Spent nuclear fuel from Canadian Research Laboratories' research reactors (e.g., NRU, and NRX) that require special transportation analysis. These spent nuclear fuels are geometrically different from an MTR-type and TRIGA spent nuclear fuel both in cross section and length, and require special shipping arrangements in addition to being transported overland by truck or rail.

2. ***MTR Spent Nuclear Fuel.*** This category covers all MTR-type spent nuclear fuels. These spent nuclear fuels have similar geometrical characteristics and use common type transportation casks.

3. ***TRIGA Spent Nuclear Fuel.*** Spent nuclear fuel from TRIGA reactors. These spent nuclear fuels also have almost similar geometrical characteristics and use common types of transportation casks.

In the case of special-type fuel, the bounding spent nuclear fuels are the RHF of France and the NRU of Canada. For the identification of a bounding spent nuclear fuel within the MTR and TRIGA fuel types, a series of ORIGEN2 (Croff, 1980) computer runs was made using different spent nuclear fuels within each fuel type. ORIGEN2 generates the radionuclide inventory in a spent nuclear fuel based on the fuel burnup, initial fissile and fertile inventory, and decay time. The radionuclide inventories of selected bounding spent nuclear fuel within each fuel type were determined assuming that the spent nuclear fuel has been cooled for a specified period after its discharge from the reactor. In order to maximize the radionuclide inventory per transportation cask, a review of the potential casks was performed. It was determined that the use of IU-04 (Pegase) transportation casks, maximizes the radioactive inventory and requires the shortest cooling period (maximum of 1 year) (see Section B.1.6). Based on this review, the cooling period for each bounding spent nuclear fuel was determined. The bounding spent nuclear fuels for MTR and TRIGA type fuel are found to be BR-2 type spent nuclear fuel, and a spent nuclear fuel from a 3-MW TRIGA reactor burning 31g (1.1 oz) of ^{235}U in 3 years, respectively. The bounding TRIGA spent nuclear fuel identified here is a theoretical bounding fuel for this category.

Table B-6 provides a list of the radioactive isotopes and their inventories for selected bounding spent nuclear fuel types. The list of isotopes is generated from ORIGEN2 output based on the following criteria:

1. All isotopes (from a list of 270 elements) that could have a potential to contribute 1 mrem from inhalation and ingestion are considered. The estimates of dose associated with each isotope intake were based on the effective committed dose equivalent factors provided in DOE/EH-0071 (DOE, 1988).

2. Once all isotopes were selected, those that contribute to 99.9 percent of total health hazard were chosen.

3. Isotopes such as ^{85}Kr, ^{235}U, and ^{238}U were added to the list as historically significant isotopes, although they do not meet the above criteria.

It is important to note that the radionuclide inventories identified here are for calculational purposes only. The majority of the spent nuclear fuels would have lower radionuclide inventories than what is identified here, and the likelihood of a full cask containing maximum inventory during the acceptance policy period would be low. By the time the policy would become effective in late 1995, there could be about 10,000 spent nuclear fuel elements, of which 80 percent would have had more than 2 years of cooldown (decay). The number of spent nuclear fuels that receive maximum burnup used in the estimation of the radionuclide inventory is very small when compared to the total number of the spent nuclear fuel elements estimated in each fuel category.

B.1.5 Characteristics and Radionuclide Inventories of Target Materials

Under Implementation Alternative 1 to Management Alternative 1 of the proposed action, DOE would plan to manage target material. The total amount of target material is estimated to be about 0.56 MTHM having a volume of 6.5 m^3 (230 ft^3). Target materials are residual materials from target fuels that have been irradiated in a research reactor to produce ^{99}Mo, which decays to ^{99}Tc, a medical isotope. Four countries (Canada, Belgium, Argentina, and Indonesia) use target fuel containing U.S.-origin enriched uranium for the production of medical isotopes. Canada, Argentina, and Belgium currently use aluminum-based targets containing HEU, and Indonesia currently uses a target that consists of a layer of HEU oxide (UO_2) material plated on the interior surface of a stainless steel tube. The distribution of target materials from these countries includes: 0.525 MTHM from Canada; 0.029 MTHM from Belgium; 0.0014 MTHM from Indonesia; and 0.0011 MTHM from Argentina. A target fuel is irradiated to a burnup level of about 3 percent (^{235}U atoms percent) before being discharged from the reactor. Once the target fuel is removed from the reactor, within a short period the fuel is dissolved and ^{99}Mo is separated from the solution. The residual material is then decayed. Prior to shipment, the residual materials are transformed to an acceptable form.

Table B-6 Bounding Radionuclide Inventories per Element for Selected Fuel Categories (Curies)

Isotope	*Fuel Category*			
	BR-2	*RHF*	*NRU*	*TRIGA*
Tritium	2.40	37	3.95	0.328
Krypton 85	68.7	1,070	113	9.10
Strontium 89	1,133	17,600	405	68.8
Strontium 90	578	8,930	967	79
Yttrium 90	578	8,930	967	79
Yttrium 91	2030	31,400	842	115
Zirconium 95	2,972	46,300	1,410	163
Niobium 95	6,111	94,900	3,060	320
Ruthenium 103	247	3,770	60.0	21.1
Rhodium 103m	247	3,770	60.0	21.1
Ruthenium 106	597	9,160	767	63.5
Rhodium 106m	597	9,160	767	63.5
Tin 123	11.9	184	10.0	0.978
Antimony 125	24.7	381	38.0	2.98
Tellurium 125m	5.89	90.6	9.21	0.718
Tellurium 127m	24.6	382	18.4	1.40
Tellurium 129m	5.25	79.8	0.958	0.578
Cesium 134	456	4,000	1,480	29.0
Cesium-137	572	8,870	958	79.8
Cerium 141	159	2,440	277	175
Cerium 144	8,667	135,000	10,600	633
Praseodymium 144	8,667	135,000	10,600	633
Promethium 147	1,342	24,600	1,240	175
Promethium 148m	2.10	29.2	0.0583	1.17
Europium 154	17.2	163	56.3	1.05
Europium 155	3.61	45.6	10.2	0.565
Uranium 234	0.0000254	0.000374	0.0000654	0.00000453
Uranium 235	0.000383	0.0109	0.000253	0.000199
Uranium 238	0.00000947	0.000206	0.00000111	0.000163
Plutonium 238	1.78	10.3	11.3	0.0760
Plutonium 239	0.0511	0.0889	0.0138	0.0138
Plutonium 240	0.0333	0.421	0.0101	0.0523
Plutonium 241	7.89	67.7	2.95	5.33
Americium 241	0.0110	0.0967	0.00517	0.0102
Americium 242m	0.0000292	0.000155	0.0000250	0.000225
Americium 243	0.000120	0.00376	0.000146	0.0000110
Curium 242	0.0486	0.127	0.0429	0.131
Curium 244	0.0369	0.00926	0.0113	0.000178
Total (Curies)	35,129	546,000	34,700	2,740
Thermal (Watts)	147	2,250	150	10.4

There are currently two methods for preparing the residual materials containing aluminum for transport. The first method is calcining and canning the material with the existing aluminum, and the second is a method that first removes aluminum from the residual materials and then oxidizes the remains. The final products are then canned. A process similar to the latter is used for the Indonesian target materials. Since the Indonesian target materials do not contain aluminum, no aluminum separation is needed. In this case, a precipitation process is used to separate the target materials from the solution. The precipitated materials are then dried and canned in preparation for transport.

The canned material from the first process contains 40 grams (1.4 oz) of ^{235}U per can. The second process allows a higher amount of ^{235}U, 200 g (7 oz), to be packed in a similar can. Can material could be aluminum or stainless steel. In the past, the target material was shipped to the Savannah River Site in aluminum cans 64 mm (2.5 in) in diameter and 280 mm (11 in) long. The use of the first process would result in a total 140 shipments of this material to the United States, and the second process would result in a total of 57 shipments. These number of shipments were estimated based on an assumption that the target material cans would be in transportation casks that would not contain other types of spent nuclear fuel. However, in all likelihood, with small amounts of target materials (such as Indonesia and Argentina), would not ship a partially filled transportation cask when other spent nuclear fuel could be added to fill the cask. Therefore, these estimates represent an upper bound on the total number of the target material shipments. The radionuclide inventory of a target material can containing from 40 to 200 g (1.4 to 7 oz) of ^{235}U, and that of a transportation cask containing this material, is given in Table B-7. This inventory is estimated based on 1 year decay time of the target material solution before the canning process.

B.1.6 Foreign Research Reactor Spent Nuclear Fuel Shipment Estimates

Tables B-1 and B-2 provide the estimated number of foreign research reactor spent nuclear fuel shipments from each country. These estimates were based on a set of assumptions that maximize the potential impacts from transportation. Review of the potential transportation casks identified eight casks with various capabilities (see Section B.2.2). These casks are certified to accommodate between 1 and 126 spent nuclear fuel elements per cask based on a variety of cask cavity configurations. Each transportation cask can be certified to ship different fuel types by using various baskets in the cask cavity. For example, a transportation cask like IU-04 has been certified to accommodate several different fuel types by using various baskets in the cask cavity. On the other hand, a cask like LHRL-120 is currently certified to accommodate only one specific fuel type (Australian HIFAR fuel). Based on this review, IU-04 was identified as the bounding cask (highest curies content for the number of elements shipped per cask) for the transportation accident analyses.

In an attempt to capture various types of spent nuclear fuel, maximize the amount of radionuclides per cask, and allow for potential partial cask shipments, for the purposes of the analyses in this EIS, the following assumptions were made to estimate the number of shipments for each type of fuel:

1. The number of shipments for MTR-type spent nuclear fuel elements was estimated based on 30 elements per cask. The radionuclide inventory per cask was estimated based on a full cask, that is, 36 spent nuclear fuel elements of the bounding MTR-type (BR-2 fuel) per cask. One exception: for the Australian spent nuclear fuel, cask LHRL-120 which was built specifically for this fuel was used for estimating the number of shipments. The allowed radionuclide inventory in this cask is the smallest of all casks identified. Nonetheless, each of the LHRL-120 casks was assumed to contain the same quantity of radionuclide inventories as that of a cask containing 36 elements of the bounding MTR-type spent nuclear fuel.

2. The number of shipments for NRU-type spent nuclear fuel was estimated based on 24 NRU elements per cask. The radionuclide inventories per cask were also based on 24 NRU elements per cask.

Table B-7 Radionuclide Inventories of Target Material per Can and per Transportation Cask (Curies)

Isotope	*Curies for 40 g ^{235}U per Can*	*Curies for 200 g ^{235}U per Can*	*Cask Curies with 40 g per Can*	*Cask Curies with 200 g per Can*
Strontium 89	4.06E+00	2.03E+01	1.95E+02	4.87E+02
Strontium 90	3.28E+00	1.64E+01	1.58E+02	3.94E+02
Yttrium 90	3.28E+00	1.64E+01	1.58E+02	3.94E+02
Yttrium	9.18E+02	3.84E+01	3.69E+02	9.22E+02
Zirconium 95	1.18E+01	5.90E+01	5.67E+02	1.42E+03
Niobium 95	2.53E+01	1.27E+02	1.21E+03	3.04E+03
Ruthenium 103	7.4E-01	3.72E+00	3.57E+01	8.93E+01
Rhodium 103m	7.5E-01	3.73E+00	3.58E+01	8.95E+01
Ruthenium 106	3.11E+00	1.55E+01	1.49E+02	3.73E+02
Rhodium 106m	3.11E+00	1.55E+01	1.49E+02	3.73E+02
Tin 123	6.0E-02	2.8E-01	2.70E+00	6.74E+00
Antimony 125	1.4E-01	6.8E-01	6.51E+00	1.63E+01
Tellurium 125m	3.0E-02	1.6E-01	1.56E+00	3.91E+00
Tellurium 127m	1.1E-01	5.6E-01	5.39E+00	1.35E+01
Tellurium 129m	1.0E-02	7.0E-02	6.7E-01	1.68E+00
Cesium 134	1.0E-02	6.0E-02	6.1E-01	1.53E+00
Cesium-137	3.26E+00	1.628E+01	1.56E+02	3.91E+02
Cerium 141	4.2E-01	2.11E+00	2.03E+01	5.07E+01
Cerium 144	4.53E+01	2.27E+02	2.18E+03	5.44E+03
Praseodymium 144	4.57E+01	2.29E+02	2.20E+03	5.49E+03
Promethium 147	1.07E+01	5.36E+01	5.14E+02	1.29E+03
Promethium 148m	5.06E-04	2.53E-03	2.43E-02	6.07E-02
Europium 154	1.65E-03	8.23E-03	7.90E-02	1.97E-01
Europium 155	6.97E-02	3.49E-01	3.35E+00	8.37E+00
Uranium 234	1.42E-07	7.09E-07	6.81E-06	1.70E-05
Uranium 235	8.29E-05	4.15E-04	3.98E-03	9.95E-03
Uranium 238	1.50E-06	7.52E-06	7.22E-05	1.80E-04
Plutonium 238	3.33E-06	1.67E-05	1.60E-04	4.00E-04
Plutonium 239	6.15E-04	3.08E-03	2.95E-02	7.38E-02
Plutonium 240	1.43E-05	7.13E-05	6.85E-04	1.71E-03
Plutonium 241	1.48E-04	7.38E-04	7.09E-03	1.77E-02
Americium 241	2.42E-07	1.21E-06	1.16E-05	2.91E-05
Americium 242m	4.43E-12	2.22E-11	2.13E-10	5.32E-10
Americium 243	3.07E-12	1.54E-11	1.47E-10	3.69E-10
Curium 242	1.43E-09	7.15E-09	6.86E-08	1.72E-07
Curium 244	3.40E-12	1.70E-11	1.63E-10	4.08E-10
Total (Curies)	1.69E+02	8.30E+02	7.97E+03	1.99E+04
Thermal (Watts)	6.8E-01	3.40E+00	3.26E+01	8.160E+01

3. The number of shipments for RHF type spent nuclear fuel was estimated based on one element per cask. The bounding cask can only accommodate one bounding spent nuclear fuel element per cask.

4. The number of shipments for TRIGA spent nuclear fuel was estimated based on 30 elements per cask. The radionuclide inventories per cask were based on 40 elements of bounding TRIGA spent nuclear fuel element per cask.

Table B-8 provides a list of radionuclide inventories per transportation cask for selected fuel categories.

Table B-8 Bounding Radionuclide Inventories per Transportation Cask for Selected Fuel Categories (Curies)

Isotope	*Fuel Category*			
	BR-2	*RHF*	*TRIGA*	*NRU*
Tritium	86.4	37.0	13.1	94.8
Krypton 85	2,470	1,070	364	2,710
Strontium 89	40,800	17,600	2,750	9,720
Strontium 90	20,800	8,930	3,160	23,200
Yttrium 90	20,800	8,930	3,160	23,200
Yttrium 91	73,000	31,400	4,580	20,200
Zirconium 95	107,000	46,300	6,500	33,800
Niobium 95	220,000	94,900	12,800	73,400
Ruthenium 103	8,900	3,770	844	1,440
Rhodium 103m	8,900	3,770	844	1,440
Ruthenium 106	21,500	9,160	2,540	18,400
Rhodium 106m	21,500	9,160	2,540	18,400
Tin 123	427	184	39.1	240
Antimony 125	890	381	119	912
Tellurium 125m	212	90.6	28.7	221
Tellurium 127m	887	382	55.8	442
Tellurium 129m	189	79.8	23.1	23.0
Cesium 134	16,400	4,000	1,160	35,400
Cesium 137	20,600	8,870	3,190	23,000
Cerium 141	5,740	2,440	7,000	6,650
Cerium 144	312,000	135,000	25,300	254,000
Praseodymium 144	312,000	135,000	25,300	254,000
Promethium 147	48,300	24,600	7,000	29,800
Promethium 148m	75.6	29.2	46.8	1.40
Europium 154	620	163	41.8	1,350
Europium 155	130	45.6	22.6	245
Uranium 234	0.000914	0.000374	0.000181	0.00157
Uranium 235	0.0138	0.0109	0.00794	0.00606
Uranium 238	0.000341	0.000206	0.00650	0.0000267
Plutonium 238	64.2	10.3	3.04	270
Plutonium 239	1.84	0.0889	0.551	0.332
Plutonium 240	1.20	0.421	2.09	0.242
Plutonium 241	284	67.7	213	70.9
Americium 241	0.396	0.0967	0.407	0.124
Americium 242m	0.00105	0.000155	0.00900	0.000600
Americium 243	0.00433	0.00376	0.000438	0.00351
Curium 242	1.75	0.127	5.25	1.03
Curium 244	1.33	0.00926	0.00713	0.270
Total (Curies)	1,260,000	546,000	110,000	833,000
Thermal (Watts)	5,290	2,250	416	3,600
Number of casks by January 2006	473	86	162	116

B.1.7 Amount of Foreign Research Reactor Spent Nuclear Fuel In Implementation Alternative 2a of Management Alternative 1

Under this implementation alternative (see Section 2.2.2.2), DOE would adopt an alternative policy duration of 5 years (1995-2000). The amount of spent nuclear fuel expected under this alternative is approximately 18,800 elements, containing approximately 13 MTHM, and having a volume of 87 m^3 (3,300 ft^3). Tables B-9 and B-10 provide an estimate of the total amount of spent nuclear fuel that would be available (i.e., currently stored or to be generated) in each country by January 2001 (Matos, 1994). These tables also provide the estimated number of shipments expected from each country. The breakdown of the number of shipments in terms of the four bounding fuel categories (as defined in Section B.1.4) are: 377 of BR-2, 56 of RHF, 154 TRIGA, and 91 of NRU type fuel shipments.

B.1.8 Distribution of Foreign Research Reactor Spent Nuclear Fuel by Fuel Type and Geography

This section summarizes the estimated amount of foreign research reactor spent nuclear fuel, in terms of fuel type and geography,[4] that could be received under different implementation alternatives of Management Alternative 1 to the proposed action. The estimated amount of spent nuclear fuel for the two policy durations (i.e., a 10-year and a 5-year spent nuclear fuel generation period) are provided in Tables B-1 and B-9, for aluminum-based fuels, and in Tables B-2 and B-10 for TRIGA fuels. These tables provide a breakdown of the estimated amount of spent nuclear fuel to be accepted from each country. Table B-11 summarizes the same information given in the above tables by fuel type and geography. The information provided in this table is the basis for the calculations of transportation (ground and marine) impacts under the basic implementation of Management Alternative 1, the proposed action to manage foreign research reactor spent nuclear fuel in the United States.

DOE is also considering a Management Alternative 3, which is a hybrid of Management Alternatives 1 and 2. Under this Management Alternative as described in Section 2.4, some of the foreign research reactor spent nuclear fuels would be reprocessed overseas, and the remaining spent nuclear fuels would be brought back to be managed in the United States. Overseas reprocessing is considered only for countries that currently have the technology and capability to store research reactor fission product high- or intermediate-level wastes. The countries that can accept research reactor fission product wastes, based on the historical evidence, are: Belgium, France, Germany, Italy, Spain, Switzerland, and the United Kingdom. Under this Management Alternative, DOE would encourage the reprocessing of aluminum-based spent nuclear fuels from the research reactors in the above countries at western European reprocessing facilities (i.e., at Dounreay Scotland, and/or other locations) and that the recovered ^{235}U be blended down and used as LEU fuel. Reprocessing spent nuclear fuels from the above countries overseas would reduce the amount of foreign research reactor spent nuclear fuels that would be managed in the United States. Table B-12 provides a distribution of the remaining foreign research reactor spent nuclear fuels by fuel type and geography that would be brought to the United States under this Hybrid Alternative. As indicated in this table, the reduction only affects spent nuclear fuels entering through the East Coast of the United States (compare Tables B-11 and B-12). It is important to note that the existing overseas reprocessing facilities have not separated ^{235}U from TRIGA fuels. This does not mean that these facilities will not be able to process TRIGA fuels in the near future. At least one facility has stated that it has a specialty plant that can reprocess small quantities of TRIGA spent nuclear fuels (UKAEA, 1994). If this

4 *Geography refers to that amount of spent nuclear fuel that is expected to arrive at an East Coast or a West Coast port of entry to the United States. Spent nuclear fuel shipments from foreign research reactors located in Europe, Africa, Middle East, and Eastern part of Central and South America are designated as East Coast shipments. All others are designated as West Coast shipments.*

Table B-9 Estimated Number of Aluminum-Based Spent Nuclear Fuel Elements of U.S.-Origin Generated by Foreign Research Reactor Operators by January 2001

Country	*Estimated Number of Spent Nuclear Fuel Elements*	*Initial Mass of Uranium, (kg)*[b]	*Estimated Number of Shipments*
Argentina[a]	283	71	9
Australia	795	247	7
Austria	130	147	4
Belgium	1,391	569	46
Brazil[a]	155	99	5
Canada	2,243	3,058	92
Chile[a]	58	12	2
Colombia[a]	16	2	1
Denmark	485	372	16
France	1,432	2,110	102
Germany	1,111	471	37
Greece[a]	199	73	6
Indonesia[a]	138	164	4
Iran[a]	29	6	1
Israel	153	34	5
Italy	150	43	5
Jamaica[a]	2	1	1
Japan	2,401	2,219	80
Korea (South)[a]	98	187	4
Netherlands	1,141	678	38
Pakistan[a]	82	16	3
Peru[a]	29	39	1
Philippines[a]	50	24	2
Portugal[a]	79	51	3
South Africa	50	10	2
Spain [c] (from Scotland)	40	16	1
Sweden	864	915	29
Switzerland	159	128	5
Taiwan	127	66	4
Thailand[a]	31	5	1
Turkey[a]	50	51	2
United Kingdom	12	4	1
Uruguay[a]	19	18	1
Venezuela[a]	120	82	4
Total	14,122	11,988	524

[a] *Countries other than high-income economies (World Bank, 1994). These are considered to be "developing" countries.*

[b] *To derive uranium mass in pounds, multiply the amount by 2.2*

[c] *40 spent nuclear fuel elements of Spain's JEN-1 reactor core are stored in Dounreay, Scotland.*

capability is acquired, then the amount of spent nuclear fuel to be managed in the United States would be lower than that indicated in Table B-12 by 834 TRIGA spent nuclear fuel elements containing 157 kg of LEU heavy metal resulting in 28 less shipments to the eastern coast of the United States by January 2005.

Table B-10 Estimated Number of TRIGA Reactor Spent Nuclear Fuel Elements of U.S.-Origin Generated by Foreign Research Reactor Operators by January 2001

Country	*Estimated Number of Spent Nuclear Fuel Elements*	*Initial Mass of Uranium (kg)*[b]	*Estimated Number of Shipments*
Austria	102	19	3
Bangladesh[a]	100	49	3
Brazil[a]	75	14	3
Finland	171	33	6
Germany	338	64	11
Indonesia[a]	233	44	7
Italy	343	64	11
Japan	321	61	11
Korea (South)[a]	320	61	11
Malaysia[a]	89	44	3
Mexico[a]	175	33	6
Philippines[a]	120	74	4
Romania [a]	1,451	189	48
Slovenia[a]	318	60	10
Taiwan	134	80	4
Thailand[a]	136	35	4
Turkey[a]	69	13	2
United Kingdom	89	17	3
Zaire[a]	132	25	4
Total	4,716	979	154

[a] *Countries other than high-income economies (World Bank, 1994). These are identified as "developing" countries.*

[b] *To derive uranium mass in pounds, multiply the amount by 2.2.*

If additional countries were to be able to accept research reactor fission product waste, additional spent nuclear fuels could be reprocessed overseas. This would reduce the amount of spent nuclear fuel to be managed in United States even further.

B.2 Transportation Casks

Spent nuclear fuel elements are transported in stainless steel packages called transportation casks, or just casks.

B.2.1 Transportation Cask Regulations

This section discusses the international and domestic regulations on transportation cask design, performance, certification, use, and transport.

B.2.1.1 International Regulations

To ensure public safety worldwide, the international community has adopted regulations for the transport of radioactive materials. The international authority for these regulations is the International Atomic Energy Agency. The emphasis of the International Atomic Energy Agency regulations for radioactive materials transport is package integrity. As promulgated in International Atomic Energy Agency Safety

Table B-11 Summary of the Distribution of Foreign Research Reactor Spent Nuclear Fuel by Fuel Type and Geography

	January 2001					*January 2006*				
	No. of Elements	*No. of Shipments*	*Initial Kg U*	*HEU Kg U*	*LEU Kg U*	*No. of Elements*	*No. of Shipments*	*Initial Kg U*	*HEU Kg U*	*LEU Kg U*
All Countries:										
1. Aluminum-Based	14,122	524	11,988	3,992	7,995	17,803	675	18,184	4,531	13,650
East[a]	10,395	419	9,024			13,186	544	13,919		
West[a]	3,727	105	2,963			4,617	131	4,263		
2. TRIGA	4,716	154	980	79	901	4,940	162	1,033	83	950
East	3,088	101	499			3,245	107	528		
West	1,628	53	481			1,695	55	505		
Developing Countries:										
1. Aluminum-Based	1,488	52	911	155	756	1,686	59	1,195	157	1,038
East	1,084	38	480			1,152	40	561		
West	404	14	431			534	19	634		
2. TRIGA	3,218	105	642	77	565	3,359	109	674	81	593
East	2,045	67	302			2,134	70	319		
West	1,173	38	340			1,225	39	355		

[a] *East refers to the eastern United States ports of entry. Spent nuclear fuel shipments from foreign research reactors located in Europe, Africa, Middle East, and eastern part of Central and South America are designated as East Coast shipments. All others are designated as West Coast shipments.*

Table B-12 Distribution of Foreign Research Reactor Spent Nuclear Fuel by Fuel Type and Geography for the Hybrid Alternative

	January 2001					*January 2006*				
	No. of Elements	*No. of Shipments*	*Initial Kg U*	*HEU Kg U*	*LEU Kg U*	*No. of Elements*	*No. of Shipments*	*Initial Kg U*	*HEU Kg U*	*LEU Kg U*
All Countries:										
1. Aluminum-Based	9,839	328	8,650	2,259	6,391	12,210	406	12,912	2,263	10,646
East[a]	6,112	223	5,687			7,593	275	8,645		
West[a]	3,727	105	2,963			4,617	131	4,263		
2. TRIGA	4,716	154	980	79	901	4,940	162	1,033	83	950
East	3,088	101	499			3,245	107	528		
West	1,628	53	481			1,695	55	505		
Developing Countries:										
1. Aluminum-Based	1,488	52	911	155	756	1,686	59	1,195	157	1,038
East	1,084	38	480			1,152	40	561		
West	404	14	431			534	19	634		
2. TRIGA	3,218	105	642	77	565	3,359	109	674	81	593
East	2,045	67	302			2,134	70	319		
West	1,173	38	340			1,225	39	355		

[a] *East Refers to the eastern United States ports of entry. Spent nuclear fuel shipments from foreign research reactors located in Europe, Africa, Middle East, and eastern part of Central and South America are designated as East Coast shipments. All others are designated as West Coast shipments.*

Series 6, radioactive materials must be transported in specially designed transportation casks that minimize the potential consequences of transportation accidents. Transportation cask designs must demonstrate their capability to ensure containment and to provide shielding by testing or analysis to the extent required by these regulations. Under International Atomic Energy Agency regulations, spent nuclear fuel transportation cask integrity must be demonstrated by successful performance during a sequence of tests that simulate accident conditions. These tests include being dropped onto an unyielding surface, dropped onto a steel post, subjected to extremely high temperatures of 800°C (1475°F) for 30 minutes, and submersed in water. Cask designs that meet these performance criteria are issued a "Certificate of Compliance" by a delegated national authority, referred to as the "Competent Authority." The Competent Authority is responsible for certifying casks that are designed or used within its "national boundary." The Competent Authority for the United States is the Department of Transportation.

To be used outside the country of origin, transportation casks must have a Certificate of Competent Authority from the country of intended use. As the Competent Authority, the Department of Transportation is responsible for granting a Certificate of Competent Authority to foreign-designed transportation casks intended for use in the United States.

B.2.1.2 Domestic Regulations

Regulations for the transport of radioactive materials in the United States are issued by the Department of Transportation, and are codified in Title 49 of the Code of Federal Regulations Parts 171-178 (49 CFR §171-178). These regulations reference accepted standards promulgated by organizations such as the International Atomic Energy Agency, the International Civil Aviation Organization, the International Air Transport Agency, the International Maritime Organization, and the U.S. Nuclear Regulatory Commission (NRC). Federal standards are updated periodically to reflect new information and to remain current with international standards, to minimize delays in international traffic, and avoid duplication of effort.

The regulation authority for radioactive materials transport is jointly shared by the Department of Transportation and NRC. As outlined in a 1979 Memorandum of Understanding with NRC, the Department of Transportation specifically regulates the carriers of spent nuclear fuel and the conditions of transport, such as routing, handling and storage, and vehicle and driver requirements. The Department of Transportation also regulates the labeling, classification, and marking of all spent nuclear fuel packages. NRC regulates the packaging and transport of spent nuclear fuel for its licensees, which include commercial shippers of spent nuclear fuel. In addition, NRC sets the standards for packages containing fissile materials and spent nuclear fuel. A detailed discussion of Federal design and performance regulations for transportation cask begins with Section B.2.1.3.

DOE policy requires compliance with applicable Federal regulations regarding domestic shipments of spent nuclear fuel. Accordingly, DOE has adopted the requirements of 10 CFR §71, "Packaging of Radioactive Material for Transport and Transportation of Radioactive Material Under Certain Conditions," and 49 CFR §171-179, "Hazardous Material Regulations." Foreign research reactor spent nuclear fuel shipments are subject to regulations set by the Department of Transportation and NRC.

B.2.1.3 Cask Design Regulations

Spent nuclear fuel is transported in robust "Type B" transportation casks that are certified for transporting radioactive materials. These transportation casks are subject to stringent design, fabrication and operating requirements imposed by the Competent Authority for the country of origin. Casks designed and certified for spent nuclear fuel transportation within the United States must meet the applicable requirements of

NRC for design, fabrication, operation, and maintenance as contained in 10 CFR §71. These regulations generally conform to International Atomic Energy Agency regulations that are presented in the International Atomic Energy Agency Safety Series 6 manual.

Cask design and fabrication can only be done by approved vendors with established quality assurance programs (10 CFR §71.101). Cask and component suppliers or vendors are required to obtain and maintain documents that prove the materials, processes, tests, instrumentation, measurements, final dimensions, and cask operating characteristics meet the design basis established in the Safety Analysis Report for Packaging for the cask, and that the cask will function as designed.

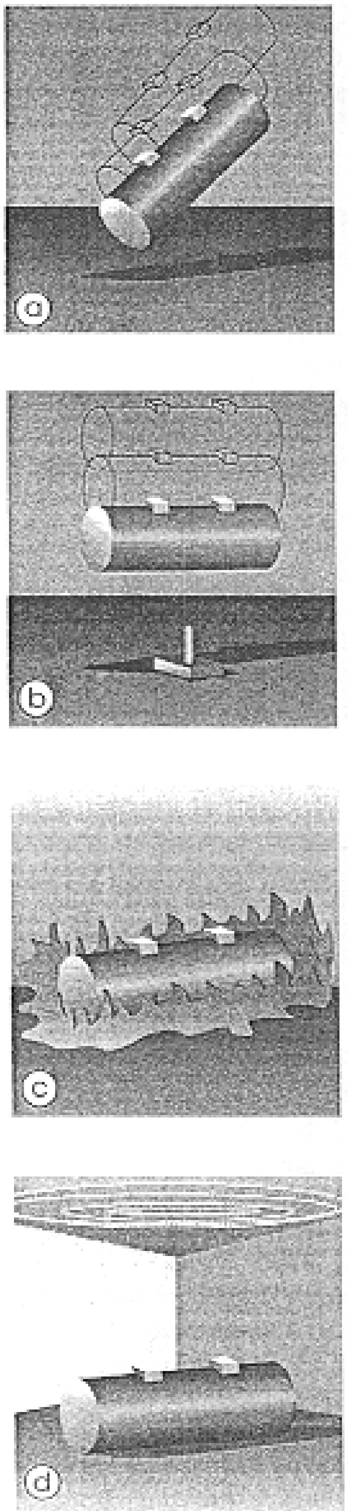
Regardless of where a transportation cask is designed, fabricated, or certified for use, it must meet certain minimum performance requirements (10 CFR §71.71-71.77). The primary function of a spent nuclear fuel transportation cask is to provide containment, criticality control, and shielding. Regulations require that casks must be operated, inspected, and maintained to high standards, ensuring their ability to contain their contents in the event of a transportation accident (10 CFR §71.87). There are no documented cases of a release of radioactive materials from spent nuclear fuel shipments even though thousands of shipments have been made by road, rail, and water transport modes. Further, a number of obsolete casks have been tested under severe accident conditions to demonstrate their adherence to design criteria without failure. Such tests have demonstrated that transportation casks are not only fabricated to a very high factor of safety; they are even sturdier than required.

Transportation casks are built out of heavy, durable structural materials, such as stainless steel. These materials must ensure cask performance under a wide range of temperatures (10 CFR §71.43). In addition to the structural materials, shielding is provided to limit radiation levels at the surface and at prescribed distances from the surface of transportation casks (10 CFR §71.47). Shielding typically consists of dense material such as lead or depleted uranium. In some cases, additional materials are added to provide neutron shielding such as water-filled outer jackets, or highly hydrogenous materials such as polyethylene. The cask cavity is configured to hold various contents including spent nuclear fuel assemblies. The assemblies are supported by internal structures or baskets that provide shock and vibration resistance, establish minimum spacing and criticality control through the use of nuclear poison materials such as boron-impregnated metals, and heat transfer to maintain the temperature of the contents within the limits specified in the Safety Analysis Report for Packaging.

Finally, to limit impact forces and minimize damage to the structural components of a cask in the event of a transportation accident, impact-absorbing structures may be attached to the exterior of the cask. These are usually composed of balsa wood, foam, or aluminum honeycomb that is designed to readily deform upon impact to absorb impact energy. All of these components are designed to work together in order to satisfy the regulatory requirements for a cask to operate under normal conditions of transportation and maintain its integrity in an accident.

Design Certification

For certification, transportation cask must be shown by analysis and/or test to withstand a series of hypothetical accident conditions. These conditions have been internationally accepted as simulating damage to transportation casks that could occur in most reasonably foreseeable accidents. The impact, fire, and water-immersion tests are considered in sequence to determine their cumulative effects on one package. These accident conditions are described in Figure B-7. The NRC recently issued revised regulations, 10 CFR Part 71, governing the transportation of radioactive materials. These regulations become effective on April 1, 1996 (NRC, 1995). The revised regulations conform with those of the International Atomic Energy Agency and current legislative requirements. The revised regulations



Standards for Spent Fuel Casks

For certification by the NRC, a cask must be shown by test or analysis to withstand a series of accident conditions. These conditions have been internationally accepted as simulating damage to spent fuel casks that could occur in most severe credible accidents. The impact, fire, and water-immersion tests are considered in sequence to determine their cumulative effects on one package. A separate cask is subjected to a deep water-immersion test. The details of the tests are as follows:

Impact

Free Drop (a) – The cask drops 30 feet onto a flat, horizontal, unyielding surface so that it strikes at its weakest point.

Puncture (b) – The cask drops 40 inches onto a 6-inch-diameter steel bar at least 8 inches long: the bar strikes the cask at its most vulnerable spot.

Fire (c)

After the impact tests, the cask is totally engulfed in a 1475°F thermal environment for 30 minutes.

Water Immersion (d)

The cask is completely submerged under at least 3 feet of water for 8 hours. A separate cask is completely immersed under 50 feet of water for 8 hours.

Figure B-7 Standards for Transportation Casks (NRC, 1987) affecting "Type B" casks require that a spent nuclear fuel transportation cask with activity greater than 10^6 curies be designed and constructed so that its undamaged containment system would withstand an external water pressure of 290 psi, or immersion in 200 m (656 ft) of water, for a period of not less than one hour without collapse, buckling, or allowing water to leak into the cask. Except for the addition of the deep water immersion test, the regulations applicable to the transportation of foreign research reactor spent nuclear fuel are unchanged.

Under the Federal certification program, a "Type B" packaging design must be supported by a Safety Analysis Report for Packaging, which demonstrates that the design meets Federal packaging standards. The Safety Analysis Report for Packaging must include a description of the proposed packaging in sufficient detail to identify the packaging accurately and provide the basis for evaluating its design. The Safety Analysis Report for Packaging must provide the evaluation of the structural design, materials properties, containment boundary, shielding capabilities, and criticality control, and present the operating procedures, acceptance testing, and maintenance program. Upon completion of a satisfactory review of the Safety Analysis Report for Packaging by NRC to verify compliance to the regulations, a Certificate of Compliance is issued.

B.2.1.4 Transportation Regulations

To assure that the transportation cask is properly prepared for transportation, trained technicians perform numerous inspections and tests (10 CFR §71.87). These tests are designed to ensure that the cask components are properly assembled and meet leak-tightness, thermal, radiation, and contamination limits. The tests and inspections are clearly identified in the Safety Analysis Report for Packaging and/or the Certificate of Compliance for each cask. Casks can only be operated by registered users who conduct operations in accordance with documented and approved quality assurance programs meeting the requirements of the regulatory authorities. Records must be maintained that document proper cask operations in accordance with the quality requirements of 10 CFR §71.91. Reports of defects or accidental mishandling must be submitted to NRC.

B.2.1.4.1 Communications

Proper communication assists in assuring safe preparation and handling of transportation casks. Communication is provided by labels, markings, placarding, and shipping papers or other documents. Labels (49 CFR §172.403) applied to the cask document the contents and the amount of radiation emanating from the cask exterior (transport index). The transport index lists the ionizing radiation level (in mrem/hr) at a distance of 1 m (3.3 ft) from the cask surface.

In addition to the label requirements, markings (49 CFR Subpart D and §173.471) should be placed on the exterior of the cask to show the proper shipping name and the consignor and consignee in case the cask is separated from its original shipping documents (40 CFR §172.203). Transportation casks are required to be permanently marked with the designation "Type B," the owner's (or fabricator's) name and address, the Certificate of Compliance number, and the gross weight (10 CFR §71.83).

Placards (49 CFR §172.500) are applied to the transport vehicle or freight container holding the transportation cask. The placards indicate the radioactive nature of the contents. In the United States, spent nuclear fuel is a Highway Route Controlled Quantity which must be placarded according to 49 CFR §172.507. Placards provide the first responders to a traffic or transportation accident with initial information about the nature of the contents.

Shipping papers should have entries identifying the following: the name of the shipper, emergency response telephone number, description of spent nuclear fuel, and the shipper's certificate as described in 49 CFR §172 Subpart C.

In addition, drivers of motor vehicles transporting spent nuclear fuel must have training in accordance with the requirements of 49 CFR §172.700. The training requirements include: familiarization with the regulations, emergency response information, and the spent nuclear fuel communication programs required by the Occupational Safety and Health Administration. Drivers are also required to have training on the procedures necessary for safe operation of the vehicle used to transport the spent nuclear fuel.

B.2.1.4.2 Marine Transport

Relevant regulations applying to transport of spent nuclear fuel by vessel are found in 10 CFR §71 and 73,[a] and 49 CFR §176. The U.S. Coast Guard, part of the Department of Transportation, inspects vessels for compliance with applicable regulations and requires 24-hour prenotification (33 CFR §160.207, 211, and 213).

49 CFR §171.12 (d) states that: "Radioactive materials being imported into or exported from the United States, or passing through the United States in the course of being shipped between places outside the United States, may be offered and accepted for shipment in accordance with International Atomic Energy Agency *Regulations for the Safe Transport of Radioactive Materials, Safety Series No. 6, 1985 Edition.*" Compliance with certain specified conditions of this section is required. For example, highway route controlled quantities of radioactive material must be shipped in accordance with appropriate provisions of the hazardous materials regulations and a Certificate of Competent Authority must be obtained, with any necessary revalidations. A Certificate of Competent Authority fulfills the International Atomic Energy Agency requirement for multilateral approval for a shipment of "Type B" packages in international commerce.

49 CFR §176.5 details the application of the regulations to vessels: "...this subchapter applies to each domestic or foreign vessel when in the navigable waters of the U.S., regardless of its character, tonnage, size, or service, and whether self-propelled or not, whether arriving or departing, underway, moored, anchored, aground, or while in drydock."

49 CFR §176.15 provides for enforcement of 49 CFR Subchapter C: "(a) An enforcement officer of the U.S. Coast Guard may at any time and at any place, within the jurisdiction of the U.S., board any vessel for the purpose of enforcement of this subchapter and inspect any shipment of hazardous materials as defined in this subchapter." Provision is also made in this section to detain a vessel which is in violation of the hazardous materials regulations.

The U.S. Coast Guard may accept a certificate of loading issued by the National Cargo Bureau, Inc., as evidence that the cargo is stowed in conformity with law and regulatory requirements. The National Cargo Bureau, Inc., is a nonprofit organization directed by Government and industry representatives (49 CFR §176.18). 49 CFR §176.18 authorizes inspectors of the National Cargo Bureau, Inc., to assist the Coast Guard in administering the hazardous materials regulations. Their functions are as follows:

"(1) Inspection of vessels for suitability for loading hazardous materials;

(2) Examination of stowage of hazardous materials;

(3) Making recommendations for stowage requirements of hazardous materials cargo; and,

(4) Issuance of certificates of loading setting forth that the stowage of hazardous materials is in accordance with the requirements of 46 U.S.C. 170 and its subchapter."

Detailed requirements for radioactive materials are located in 49 CFR §176 Subpart M of the Hazardous Materials Regulations. General radioactive material stowage requirements state that "(b) A package of radioactive materials which in still air has a surface temperature more than 5°C (9°F) above the ambient air may not be overstowed with any other cargo. If the package is stowed under the deck, the hold or compartment in which it is stowed must be ventilated," (49 CFR § 176.700).

Except for exclusive-use shipments, requirements relating to transport indexes state that:

> ". . . the number of freight containers with packages of radioactive materials contained therein must be limited so that the total sum of the transport indexes in the containers in any hold or defined deck area does not exceed 200, and:
>
> (1) The sum of transport indexes for any individual freight container, or group of freight containers, does not exceed 50; and,
>
> (2) Each freight container or group of freight containers is (are) handled and stowed in such a manner that groups are separated from each other by a distance of at least six m (20 ft)," [49 CFR § 176.704(c)].

Section 176.76(a) includes provision for freight containers with hazardous materials to be carried onboard a vessel in accordance with the following:

> " (1) The material must be in proper condition for transportation according to the requirements of this subchapter;
>
> (2) All packages in the transport vehicle or container must be secured to prevent movement in any direction. However, vertical restraint is not required if the shape of the packages and the stuffing pattern precludes shifting of the load;
>
> (3) Bulkheads made of dunnage which extend to the level of the cargo must be provided unless the packages are stowed flush with the sides or ends;
>
> (4) Dunnage must be secured to the floor when the cargo consists of dense materials or heavy packages."

Each freight container must be placarded as required by 49 CFR §172 Subpart F of the Hazardous Materials Regulations [176.76(f)].

Section 176.80 requires that radioactive materials be segregated from other hazardous materials so that they do not interact dangerously in an accident, or alternatively, requires that the radioactive material be in separate holds when stored under deck. In 49 CFR §176.83(b), a table is provided (Table II) that specifies the minimum separation distances for different classes of hazardous materials onboard a vessel. A minimum horizontal separation distance of 3 m (10 ft) projected vertically from the reference package is required. For specified hazardous materials, the "separate from" requirement means that the materials must be placed in separate holds when stowed under deck.

B.2.1.4.3 Ground Transport

Overland shipments (by railcar or by truck) are regulated by a variety of the Department of Transportation and NRC regulations dealing with packaging, notification, escorts, and communications. In addition, there are specific regulations for carriage by rail and carriage by truck.

When provisions are made to secure a package so that its position within the transport vehicle remains fixed during transport, with no loading or unloading between the beginning and end of transport, a package shipped overland in exclusive-use closed transport vehicles may not exceed the following radiation levels as provided in 49 CFR §173.441(b):

- 1,000 mrem/hr on the external package surface;
- 200 mrem/hr at any point on the outer surface of the vehicle;
- 10 mrem/hr at any point 2 m from the vertical planes projected from the outer edges of the vehicle;
- 2 mrem/hr in any normally occupied position in the vehicle, except that this provision does not apply to private motor carriers when the personnel are operating under a radiation protection program and wear radiation-exposure monitoring devices.

The shipper of record must comply with the requirements of 10 CFR §71.5 and §73.37. Section 71.5 provides that all overland shipments must be in compliance with the Department of Transportation and NRC regulations; these regulations provide for security of irradiated reactor fuel. General requirements include: providing notification to NRC in advance of each shipment, developing a shipping plan, providing escort instructions, establishing a communications center to be staffed 24 hours a day, making arrangements with local law enforcement agencies along the route for their response (if not using law enforcement personnel as escort), ensuring that the escorts are trained in accordance with Section 73.37 Appendix D, and ensuring that escorts make notification calls every 2 hours to the communications center. Additional requirements include having two armed escorts within heavily populated areas (when not in heavily populated areas, only one escort is needed) and the capability of communicating with the communications center and local law enforcement agencies through a radiotelephone or other NRC approved means of two-way voice communication.

The shipper of record, as required by 49 CFR §173.22, provides physical security measures for spent nuclear fuel shipments equivalent to those of NRC. The shipper, or the shipper's agent, provides notification for unclassified spent fuel shipments to State officials.

B.2.1.4.3.1 Rail Transport

Rail transportation requirements for radioactive materials are contained in 49 CFR §174. Briefly, for rail shipments of spent nuclear fuel the following additional requirements apply:

- railcars carrying radioactive materials must be segregated from other cars within a train, and cannot be next to other placarded hazardous materials (49 CFR §174.85) or occupied engines or cabooses; and
- hazardous materials shipments (including radioactive) must be expedited (49 CFR §174.14).

In addition, Association of American Railroad Interchange rules require that spent nuclear fuel be shipped only on railcars meeting certain construction and packaging retention requirements (AAR Rule 88A 1d). Rail routing has not been regulated by the Department of Transportation because the railroads are privately-owned companies. However, rail routes used for spent nuclear fuel shipping must be approved by NRC under a physical security plan (10 CFR §73.37).

B.2.1.4.3.2 Truck Transport

Truck transportation requirements for radioactive materials are contained within 49 CFR §177.800. In addition to requirements for securement and segregation by total transport index (50), there are road routing requirements as well. For carriage by truck, the carrier will use interstate highways or State-designated preferred routes for movement of radioactive materials in conformity with the Department of Transportation rulemaking, Docket HM-164. These regulations, found in 49 CFR, Subpart D, establish routing and driver training requirements for highway carriers of packages containing "highway-route-controlled quantities" of radioactive materials. Spent nuclear fuel shipments constitute such quantities. The Department of Transportation also issues road operating requirements for radioactive materials shipments, including parking and operating rules. Primarily, these rules require trucks to stop and undergo visual inspection by the driver every 160 km (100 mi). Domestic road routing must also be approved by NRC under a physical security plan.

Many State and local governments have established their own rules, specifying such things as prenotification requirements, time-of-day restrictions, routes, and special equipment. State and local regulations that unnecessarily burden, delay, or ban shipments of radioactive materials will be preempted under the Hazardous Materials Transportation Act. The Department of Transportation rules make routing designation by appropriate State agencies enforceable by the Federal Government according to a determination by the Department of Transportation that such route designations are likely to result in further reduction of radiological risk.

B.2.2 Potential Transportation Casks

This section provides a description of the transportation casks that could be used for marine and ground transport of foreign research reactor spent nuclear fuel. The casks were identified from a review of the "Directory of National Competent Authorities' Approval Certificates for Package Design, Special Form Material, and Shipment of Radioactive Material, 1993 Edition," and the RAMPAC (radioactive material package) database for certified radioactive materials packaging (NRC, 1993). The review included only those transportation casks with current "Type B" designations for spent nuclear fuel.

B.2.2.1 Marine Transport

Table B-13 identifies the potential transportation casks for marine transport of foreign research reactor spent nuclear fuel. Each of these casks has both a certification from the country of origin and a certificate of competent authority from the Department of Transportation, which is designated as the Competent Authority for the United States. Except for the Unifetch, each of the casks has been previously used or accepted for use by DOE.

Table B-13 Proposed Transportation Casks for Marine Transport

Transportation Cask	*Certificate*	*DOE Experience*	*Country of Origin*
LHRL-120	USA/0389/B(U)F	Yes	Australia
GNS-11	USA/0381/B(U)F	Yes	Germany
TN-1	USA/0316/B(U)F	Yes	Germany
IU-04	USA/0100/B(U)F	Yes	France
TN-7 (TN-7/2)	USA/0130/B(U)F	Yes	Germany
NAC-LWT	USA/9225/B(U)F	Yes	United States
Unifetch	GB/1113/B(M)F	No	Great Britain
Goslar	USA/0094/B(M)F	Yes	Germany

Table B-14 summarizes the essential characteristics of the marine transportation casks for foreign research reactor spent nuclear fuel, such as physical dimensions, weight, type, and quantity of spent nuclear fuel elements each cask can accommodate, cooling time before shipment, maximum activity content in a cask, and the maximum initial ^{235}U content of each element. A summary of important characteristics of these casks is also provided after Table B-14.

Table B-14 Transportation Cask Design Characteristics for Marine Transport

Shipping Cask	*Weight (MT)*	*^{235}U g/Elements*	*Fuel Type*	*Number of Elements per Cask*	*Cooling Time (Days)/Activity per Cask (kCi)*	*Cask Dimensions (mm)*
LHRL-120	21.4	150-170	MTR tubular (HIFAR)	114	2,557/80	H: 3,400 D: 2,300
GNS-11	13.6	173 323	Tubular MTR Boxed-type MTR	21-28 33	180/41 180/27	H: 1,460 D: 1,185
TN-1	18.4	NA	Boxed-type MTR	126	NA	H: 2,910 D: 950
IU-04	18.9	Varied: 150-8600	Special Tubular Boxed-type MTR TRIGA Spent Nuclear Fuel	1 36-40 40-44	about one yr/1,250	H: 2,240 D: 1,880
TN-7 (TN-7/2)	25.5 (24.5)	290 8,500	Tubular-Boxed type MTR Special	60-64 2	250-1,780/2,000 310/2,000	H: 3,155 D: 1,030
NAC-LWT	23.2	17,575 Natural* 354	Commercial PWR Commercial BWR Metallic Rod Boxed-type MTR	1 - PWR 2 - BWR 15 - Met. Rods 42	730 - PWR 730 - BWR 365 - Met. Rods 1,095	H: 5,100 D: 1,120
Unifetch	16.9	405 170	Tubular Boxed-type MTR	24 40	90/45.4 90/123	H: 2,100 D: 1,800
Goslar	10.9	320	Boxed-type MTR	13	120/960	H: 1,460 D: 1,190

**Natural = Maximum initial U^{235} is 0.711 weight percent*

NA = Not Available

PWR = Pressurized Water Reactor

BWR = Boiling Water Reactor

LHRL-120

The LHRL-120 consists of a cylindrical cask surrounded by an impact limiter supported on cradles attached to a skid that is bolted to the base of a shipping container. The cask is a right circular cylinder with two concentric walls of steel for structural strength, with the annular area between the walls. The inner shell forms the containment.

The cask is built of inner and outer shells welded to the bottom end closure plate and top bolt ring, and secured by a bolted lid with a double o-ring seal. The annular space between the shells is filled with lead and supplementary lead shielding plates are provided on the bottom end closure plate and lid. The cask has two external lifting trunnions and, except for the high strength steel bolts, lead shielding, and synthetic rubber o-ring, is constructed of stainless steel plugs.

The impact limiter consists of a steel shell filled with dense polyurethane foam arranged to provide energy absorption and thermal insulation.

During transport, the cask body is completely enclosed by an impact limiter which provides both thermal and impact protection. The impact limiter is constructed in two pieces which bolt together and surround the cask body. LHRL-120 is designed for passive cooling by means of cooling tubes that penetrate the impact limiter. Tubes in the bottom half also transfer loads to the cradles. The cask and the impact limiter are secured to the skid by two tie-down straps and restraints. The skid is bolted to the base of an open conventional shipping container and is in turn enclosed by a steel weather cover fitting inside the end walls of the container and bolted to the container base. The container has standard International Standards Organization lifting arrangements and is approved under the international convention for safe containers.

The length and diameter of the cask with the impact limiter are 3.4 m (134 in) and 2.3 m (91 in), respectively. The total mass of the cask with contents, impact limiter, skid and tie-downs is 21.36 metric tons (47,080 lb) and the gross mass of the package including lift yoke, bolt tooling, tool box, weather cover and shipping container is approximately 24 metric tons (52,800 lb).

The cask was designed by Eggers, Ridelhalgh, and Partners of Columbus, Ohio for spent nuclear fuel from the High Flux Australian Research Reactor (HIFAR).

Permitted Contents:

Irradiated spent nuclear fuel elements with a minimum decay period of 7 years

Maximum number of fuel elements per package	120[a]
Maximum fuel mass	554 kg (1,200 lb)
Maximum decay heat	290 Watts
Maximum mass of both baskets (empty)	891 kg (1,965 lb)
Maximum activity of package	80,000 Ci ($3.0 \times 10^{+15}$ Bq)
Transport Index	50

[a] *The maximum number allowed is 114.*

Two identical baskets are authorized for the LHRL-120 cask in a 1 x 2 array, (i.e., in a stacked configuration). The baskets are constructed exclusively of aluminum alloys 6061 and 6063. Each basket contains 60 cells, each providing an 11-cm- (4.3-in-) diameter by 65-cm- (25.75-in-) high cylindrical cavity for each fuel assembly. Only 57 of the cells are loaded with fuel elements; the 3 center-most positions are left unloaded. The nominal wall thickness of the cell is 6.4 mm (0.25 in). Maximum mass of both baskets tiers (empty) is 891 kg (1,965 lb).

GNS-11

The GNS-11 consists of a welded stainless steel/lead construction which is tightly closed with a primary lid. The cask body can be closed at the lid region with a protection plate. The spent nuclear fuel elements fit into a fuel basket which is inserted in the cask cavity. The cask is an upright circular cylinder with two concentric walls of steel for structural strength with the annular area between the walls filled with lead for radiation shielding. The inner steel shell forms the containment.

The containment system is formed by the cask body, the primary lid including elastomer seal rings, plugs, and boltings. During transport, hood shaped impact limiters consisting of steel plates with a soft wood filling are attached to the top and bottom of the cask. In the upper region, two trunnions are screwed to the cask body for handling. The cask has the following external dimensions:

Diameter (without impact limiters)	1,185 mm (46.7 in)
Diameter (with impact limiters)	1,355 mm (53.4 in)
Height (cask body)	1,460 mm (57.5 in)
Height (with impact limiters)	1,780 mm (70 in)

The cask body is protected during transport by top and bottom impact limiters while the cask is secured vertically on its low-boy transporter. The cask weighs about 13.6 metric tons (30,000 lb). The cask can be used to ship up to 28 tubular-type MTR elements and up to 33 box-type MTR elements with initial ^{235}U enrichment of up to 93 percent. In addition, the cask can also be used to transport other types of irradiated hardware. This cask is shown in Figure B-8.

Since the temperature on the outside of the package may exceed 50°C (122°F) and the transport index can be greater than 10, the package is to be transported as a full load or as a closed load. Therefore, a maximum of two casks could be fixed in a shipping container. The cask was designed and manufactured by the German company Gessellschaft fur Nuklear-Behalte GmbH. There are currently two GNS-11 casks available for use.

Permitted Contents:

Three different fuel baskets are authorized for use with this cask. These accommodate various types and amounts of fuel:

1. A maximum of 21 or 28 (depending on the type of fuel basket used) irradiated tubular MTR fuel elements consisting of 3 to 5 concentrically arranged fuel tubes, with the following further specifications per fuel element:

Maximum initial enrichment	80 percent
Chemical form	U-Al alloy
Maximum initial mass of ^{235}U	173.4 g (6 oz)
Maximum initial quantity of uranium	217.0 g (7.5 oz)
Maximum active length	61 cm (24 in)
Maximum diameter of outer tube	10.3 cm (4 in)
Minimum cooling time	180 days

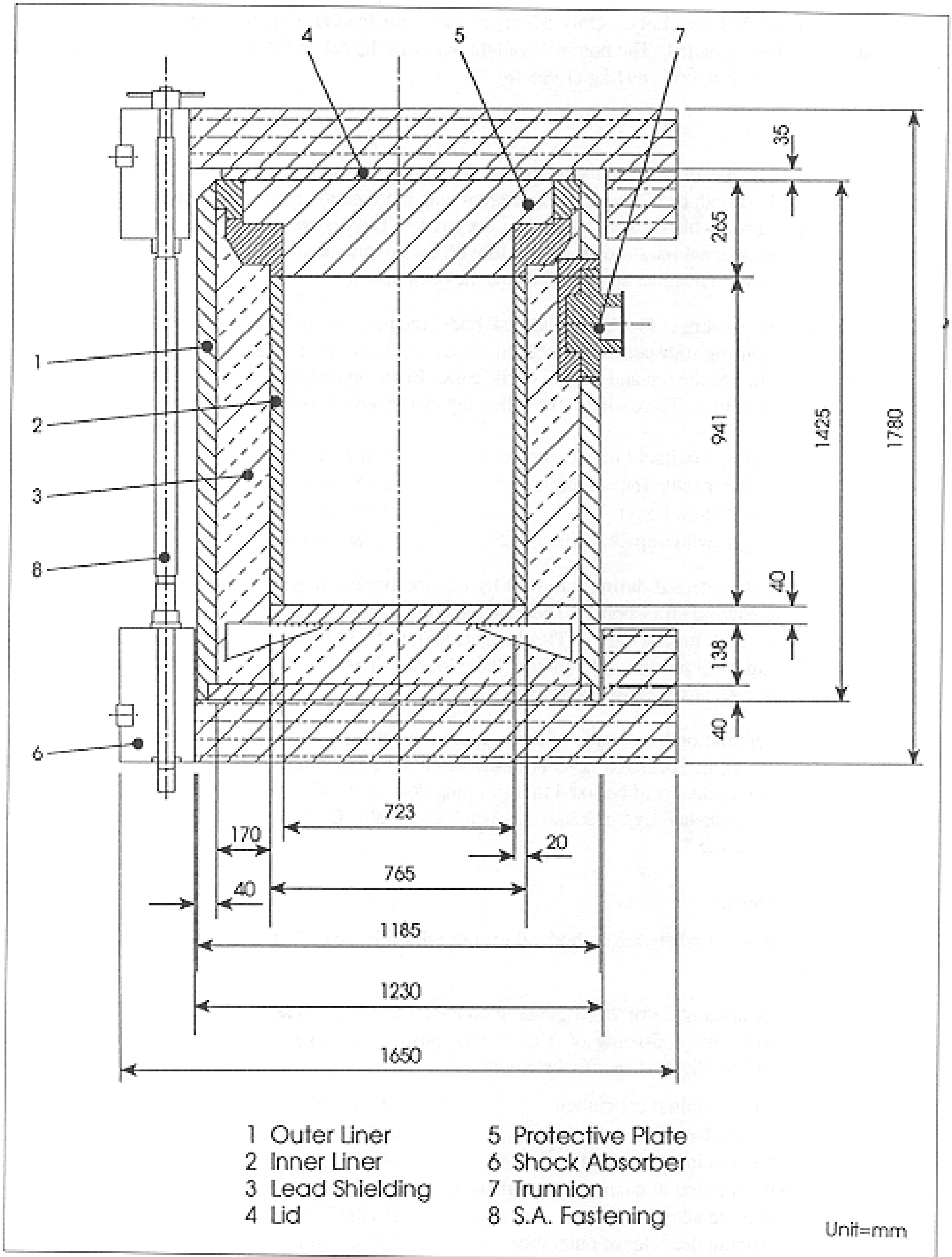


Figure B-8 GNS Shipping Cask

Thermal power (average)	maximum 76 Watts (for 21 fuel elements per cask)
Thermal power (average)	maximum 57 Watts (for 28 fuel elements per cask)
Maximum activity	40.5 kCi (1.5 PBq)

2. A maximum of 33 irradiated boxed-type MTR fuel elements, each containing a maximum of 23 aluminum-based fuel plates, with the following further specifications per fuel element:

Maximum initial enrichment	93 percent
Maximum initial mass of ^{235}U	268 g (9.3 oz)
Maximum initial mass of uranium	335 g (11.6 oz)
Active length	maximum 61 cm (24 in)
Cross-sectional area	approx. 81 x 76 mm (3.2 x 3.0 in)
Minimum cooling time	180 days
Thermal power (average)	maximum 48.5 Watts
Maximum activity	27 kCi (1 PBq)

3) A maximum of 33 irradiated boxed-type MTR-fuel elements each containing a maximum of 23 aluminum-based LEU fuel plates (containing dispersed U_3Si_2 or U_3O_8) with the following further specifications per fuel element:

Maximum initial enrichment	20 percent
Maximum initial mass of ^{235}U	323 g (11.2 oz)
Maximum initial mass of uranium	1,635 g (3.6 lbs)
Active length	maximum 61 cm (24 in)
Cross-sectional area	approx. 81 x 76 mm (3.2 x 3 in)
Minimum cooling time	360 days
Thermal power (average)	maximum 48.5 Watts
Activity	maximum 27 kCi (1 PBq)

TN-1

The TN-1 is a cylindrical double-walled steel container with lead and plaster for shielding. It is constructed of steel structural shells with the annulus between them filled with lead for gamma shielding and plaster as a heat shield. Additional heat insulation and impact resistance is provided by impact limiters. The cask, with the impact limiters, weighs 18.37 metric tons (40,500 lb). The internal cavity can accommodate three baskets, one on top of the other, each filled with up to 42 boxed-type MTR fuel elements of initial ^{235}U enrichment of up to 94 percent.

The containment system is formed by the cask body, lid with its "elastomer" seals and bolts, and three sealing plates with "elastomer" seal rings in the cask body via the quick connections.

Physical dimensions of TN-1 are as follows:

	Without Shock Absorber	*With Shock Absorber*
Width	950 mm (37.4 in)	1,284 mm (50.6 in)
Height	920 mm (36.2 in)	1,254 mm (49.4 in)
Length	2,910 mm (114.6 in)	3,075 mm (121 in)

TN-1 is designed by the French company Cogema. It is shipped in the horizontal position with the top and bottom impact limiters attached. The TN-1 cask is shown in Figure B-9.

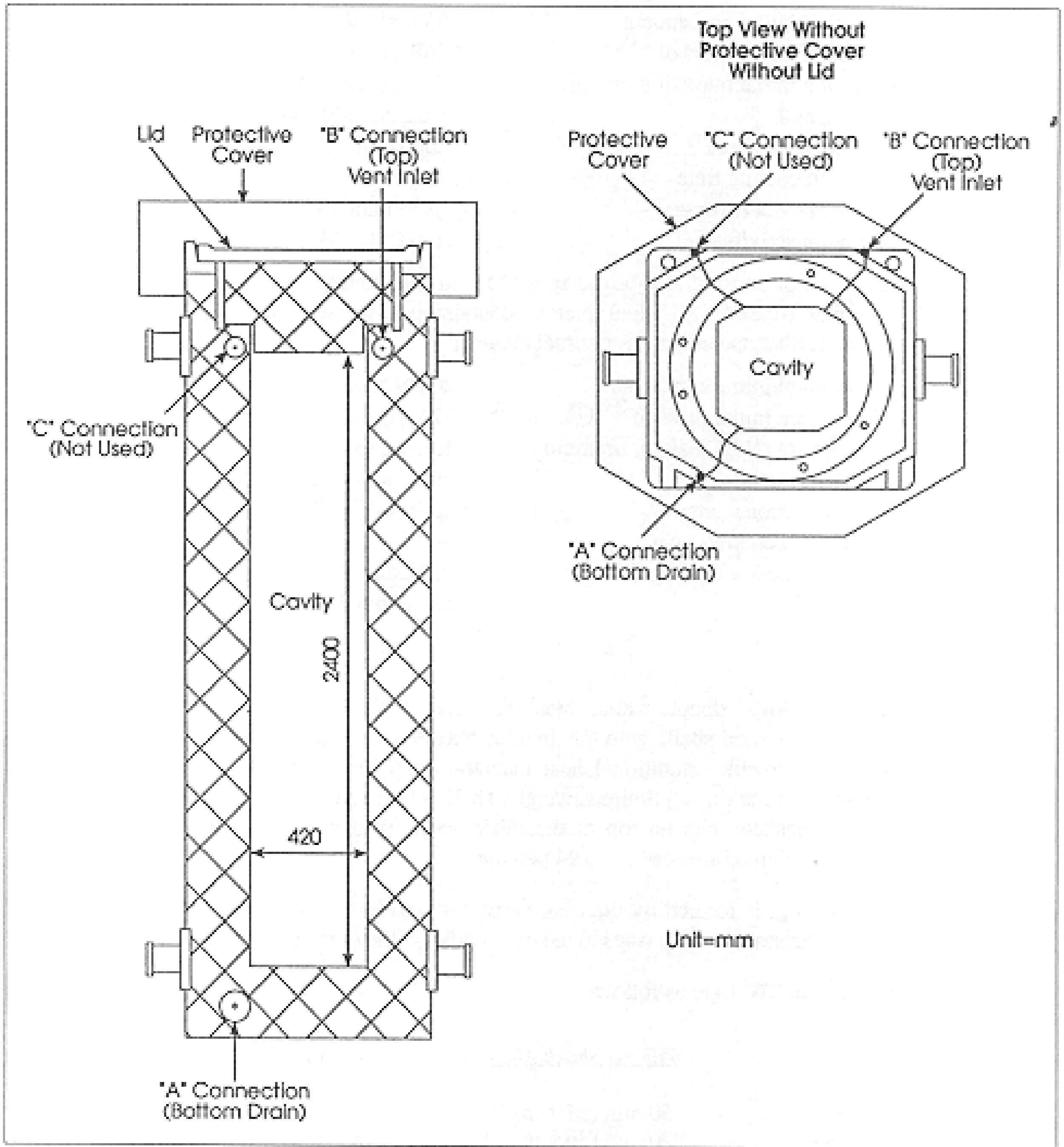


Figure B-9 TN-1 Shipping Cask

IU-04

The IU-04, also known as Pegase, consists of a body built of two stainless steel shells enclosing a lead shield. The inner confinement shell and the lead shield form a solid unit constituting the body. The outer shell is provided with a base plate filled with asbestos and is fitted with cooling fins. A layer of plaster is placed between the bottom of the outer shell and the lead. The steel lid is filled with lead and plaster. There are two pipe systems connecting the inner tank to the outside.

The cask is a right circular cylinder with two concentric walls of steel for structural strength with the annular area between the walls filled with lead for radiation shielding. The inner steel shell forms the containment. The IU-04 inner cavity can accommodate a variety of baskets which may be used to transport both MTR and TRIGA spent nuclear fuel. The cask weighs approximately 18.9 metric tons (41,670 lb). It is transported in the vertical position on the pallet, with top and bottom impact limiters to protect it in the event of an accident.

There is a main protective cover of stainless steel filled with balsa wood of two different densities. There are covers of mild steel protecting the pipe outlets which are filled with plaster. Like TN-1, this cask was also designed by Cogema. The IU-04 cask is shown in Figure B-10.

The cask is authorized to be used with various baskets designed for different types of spent nuclear fuel. The following summarizes a selected number of baskets designed for IU-04 casks:

1. Basket AA-267 - consists of cylindrical aluminum grid, 960 mm (37.8 in) high, containing 40 channels of square cross section, 84 x 84 mm (3.3 x 3.3 in), and 4 channels of cross section, 72 x 72 mm (2.83 x 2.83 in). The grid is surrounded by an aluminum belt with outside diameter of 795 mm (31.3 in). The aluminum contains two percent boron. The bottom end is covered by a 15-mm- (0.6-in-) thick aluminum plate welded to the cylindrical belt. It contains drain orifices.

Diameter	795 mm (31.3 in)
Total Height	1,030 mm (40.6 in)
Useful Height	960 mm (37.8 in)
Approx. Weight	360 kg (793.7 lbs)

   A total of 44 MTR boxed-type (72 x 72 mm cross section) fuel elements can be put in this basket. The maximum allowed residual thermal power per element is less than 80 Watts.

2. Basket TN-9083 - consists of a block of stainless steel containing five percent boron. The basket is 895 mm (35.2 in) long and has 36 lodgments of 81 x 87 mm (3.2 x 3.4 in) cross section, bored to a diameter of 98 mm (3.9 in). The bottom is covered by a plate, 12 mm (0.5 in) thick, fastened to the block by screws. The bottom plate contains drain orifices of 50 mm (2 in) diameter. The dimensions of the basket are as follows:

Base Height	90 mm (3.5 in)
Diameter	796 mm (31.3 in)
Total Height	907 mm (35.7 in)
Useful Height	895 mm (35.2 in)
Approx. Weight	1,410 kg (3,108 lbs)

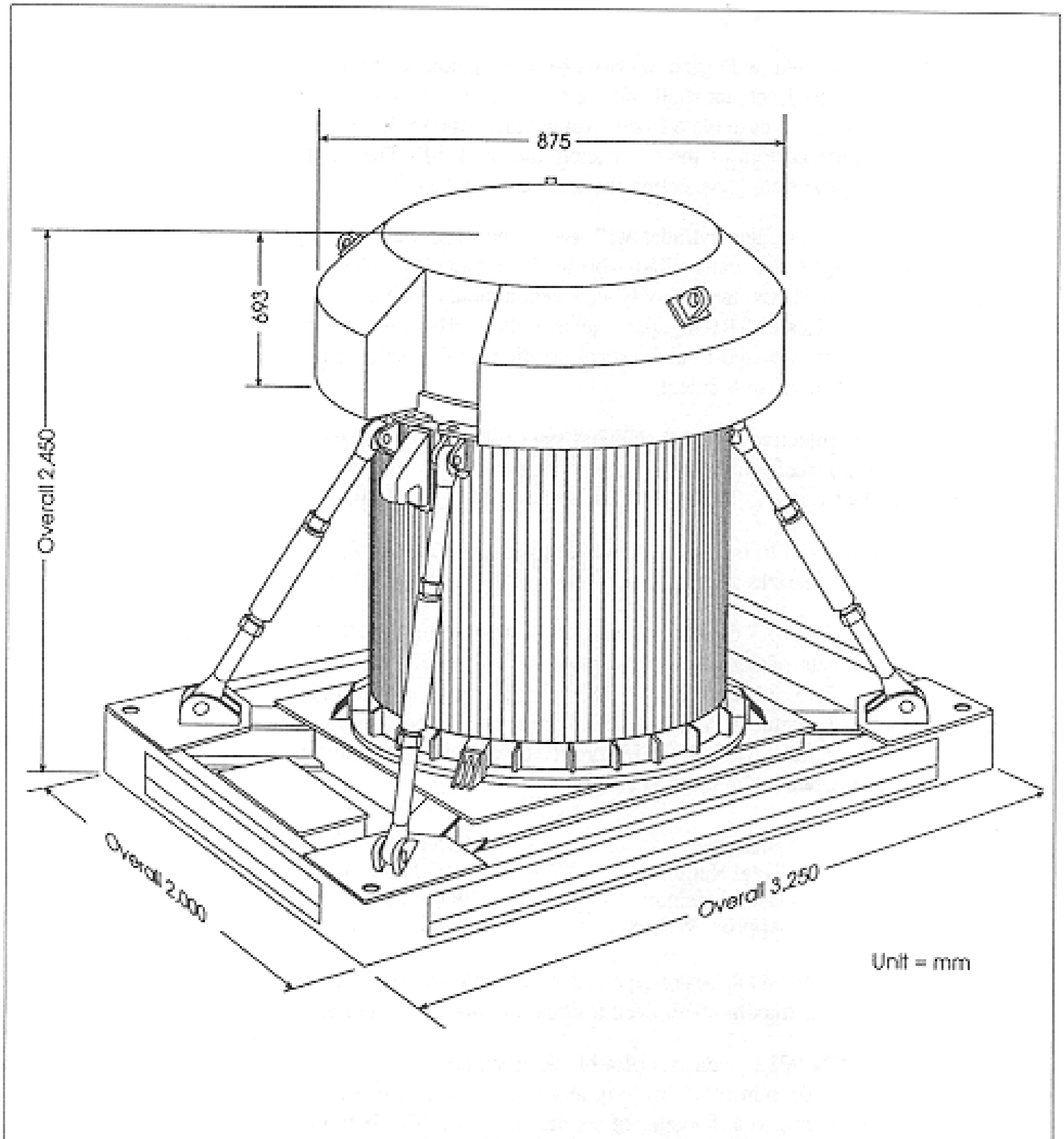


Figure B-10 IU-04 Shipping Cask

A maximum of 36 MTR tubular type fuel elements can be put in this basket. The maximum residual thermal power of each spent nuclear fuel must be less than 132 Watts.

Basket TN-9083 can also be used for TRIGA spent nuclear fuel. The maximum ^{235}U content of each TRIGA spent nuclear fuel element must be less than 40 g (1.4 oz).

3. Basket AA-49 - consists of 5 sectors of Copper-Cadmium alloy (at least 2 percent Cadmium by weight) with 5 square channels of 84 x 84 mm (3.3 x 3.3 in) and 1 channel of 71.5 x 71.5 mm (2.8 x 2.8 in), and a central core in stainless steel with a system for fastening the sectors.

Diameter	800 mm (31.5 in)
Total Height	1,030 mm (40.6 in)
Useful Height	970 mm (38.2 in)
Approx. Weight	2,500 kg (5,511 lbs)

Basket AA-49 accommodates 30 fuel elements of 93 percent enrichment from BR-2 with a maximum allowable residual power of 266 Watts per element.

4. Basket AA-50 - consists of 6 sectors of Copper-Cadmium alloy (at least 2 percent Cadmium by weight) with 6 channels of rectangular cross section 86 x 77.5 mm (3.4 x 3.1 in), and a central core in stainless steel with a system for fastening the sectors.

Diameter	800 mm (31.5 in)
Total Height	1,030 mm (40.6 in)
Useful Height	970 mm (38.2 in)
Approx. Weight	1,996 kg (4,400 lbs)

Basket AA-50 accommodates 36 boxed-type MTR fuel elements of up 93 percent enrichment. Maximum allowable residual power per each element is 200 Watts.

5. Basket AA-117 - is fabricated in Z2-CN-18-10 stainless steel with a base plate 10 mm (0.4 in) thick drilled with water drain holes in the center, 4 vertical posts 10 mm (0.4 in) thick bolted to the base plate and connected together by 3 circular spacers. Basket AA-117 accommodates 1 fuel element of 93.5 percent enrichment from RHF with a maximum allowable residual thermal power of less than 3,000 Watts.

Diameter	797 mm (31.4 in)
Total Height	1,030 mm (40.6 in)
Useful Height	420 mm (16.5 in)
Approx. Weight	165 kg (364 lbs)

TN-7 (TN-7/2)

The TN-7 consists of a cylindrical stainless steel exterior container with corresponding stainless steel lid with an integrated lead shielding; four trunnions; one bottom shock absorber; and a stainless steel, concentric cylindrical interior container, which together with its lead constitutes the "tight enclosure." Between the interior and the exterior container there is a lead shielding, 185 mm (7.3 in) thick at the sides, and 170 mm (6.7 in) thick at the lid. This shielding is surrounded by a humid cement thermal insulation. Within the interior container, up to four racks can be stacked upon each other for the admissible contents mentioned above.

The cask is a right circular cylinder with two concentric walls of steel for structural strength. The annular area between the steel walls is filled with lead for radiation shielding. The inner steel shell forms the containment.

The cask weighs about 25.5 metric tons (56,220 lb). The TN-7 was originally designed for the transportation of short light water reactor spent nuclear fuel but has the capability to accommodate the highly-enriched MTR spent nuclear fuel. In this capacity, the 4 baskets that fit in the inner cavity can accommodate up to 15 tubular or 16 box-type MTR fuel elements each.

The cask is transported in the horizontal position with top and bottom impact limiters providing protection in the event of an accident.

The TN-7/2 is very similar in design and dimension to the TN-7. The TN-7/2 is used to transport the same types and quantities of spent nuclear fuel as the TN-7. In addition, it can be used to transport up to 64 box-type MTR spent nuclear fuel elements or 2 RHF special spent nuclear fuel elements. The TN-7/2 is transported the same way as the TN-7. There is one TN-7 cask available for use at the present time. This cask has been designed by the German company Transnuklear GmbH.

Permitted contents:

1) Up to four insert racks, containing per rack:

   - maximum 15 irradiated tubular-type MTR fuel elements, each containing a maximum of 250 g (8.7 oz) of uranium enriched between 80 and 93 percent with a maximum of 200 g (6.9 oz) of ^{235}U in the form of a U-Al alloy, with a minimum cooling time of 250 days and a maximum activity of 40 kCi (1.48 PBq), or

   - maximum 16 irradiated Boxed-type MTR fuel elements, each containing a maximum of 363 g (12.6 oz) of uranium enriched between 80 and 93 percent, with a maximum of 290 g (10.1 oz) of ^{235}U in the form of a U-Al alloy, with a minimum cooling time of 1,780 days and a maximum activity of 20 kCi (740 TBq).

The racks can be combined within a cask, provided that the maximum thermal powers do not exceed 125 Watts per fuel element; 1,125 kW per rack; and 4.5 kW per cask.

OR

2) Up to two irradiated RHF type fuels, or a fuel containing a maximum number of 280 fuel plates each, with an active fuel length of about 900 mm (35.4 in), containing originally a maximum of 9.32 kg (20.6 lbs) of uranium enriched to 93 percent of ^{235}U with a maximum of 8.67 kg (19.1 lbs) of ^{235}U in the form of a U-Al alloy per element.

Maximum activity per fuel element	1,000 kCi (37 PBq)
Thermal output per fuel element	maximum 2.25 kW
Cooling time	310 days

TN-7 is authorized as Fissile Class II with a minimum Transport Index of 8.3 per package.

NAC-LWT

NAC-LWT is a steel encased lead shielded transportation cask. The cask body consists of a 19-mm- (0.75-in-) thick stainless steel inner shell, a 146-mm- (5.75-in-) thick lead gamma shield, a 30-mm- (1.2-in-) thick stainless steel outer shell, and a neutron shield tank. The inner and outer shells are welded to a 101.6-mm- (4-in-) thick stainless steel bottom and forging. The cask bottom consists of a 76.2-mm- (3-in-) thick, 52.7-cm- (20.75-in-) diameter lead disk enclosed by a 88.9-mm- (3.5-in-) thick stainless steel plate and bottom end forging. The cask lid is a 287-mm- (11.3-in-) thick ring stainless steel stepped design, secured to a 362-mm- (14.25-in-) thick ring forging with twelve 25.4-mm- (1-in-) diameter bolts. The cask seal is a metallic O-ring. A second teflon O-ring and a test port are provided to leak test the seal. Other penetrations in the cask cavity include the fill and drain ports, which are sealed with port covers and teflon O-rings. The cask weighs about 22.4 metric tons (51,200 lb) including a maximum of 1.75 metric tons (4,000 lb) weight of fuel and basket.

The neutron shield tank consists of a 6.1-mm- (0.24-in-) thick stainless steel shell with 12.7-mm- (0.50-in-) thick end plates. The neutron shield region is 416.5 cm (164 in) long and 127 mm (5 in) thick. The neutron shield tank contains an ethylene glycol/water solution that is 1 percent boron by weight.

The overall dimensions of the package, with impact limiters, are 5.9 m (232 in) long by 165.1 cm (65 in) diameter. The cask cavity is 4.52 m (178 in) long and 340 mm (13.4 in) in diameter, having a volume of about 0.41 m^3 (14.5 ft^3). The cask is equipped with aluminum honeycomb impact limiters. The top impact limiter has an outside diameter of 165.7 cm (65.25 in) and a maximum thickness of 71.9 cm (28.3 in). Both impact limiters extend 30.5 cm (12 in) along the side of the cask body. The cask is transported in the horizontal position.

NAC-LWT is designed to transport one pressurized water reactor assembly, two boiling water reactor assemblies, up to 15 metallic fuel rods, or 42 boxed-type MTR foreign research reactor spent nuclear fuel with a proper basket design. There are several NAC-LWT casks available which could be used to transport foreign research reactor spent nuclear fuel. It is designed by the Nuclear Assurance Corporation in the United States.

Unifetch

Unifetch was originally designed for the transport of the spent nuclear fuel from the BR-2 (Belgium reactor). The cask weighs about 18.6 metric tons (41,000 lbs) and can accommodate either 24 or 40 spent nuclear fuel elements. The cask is transported in the vertical position. Unifetch is designed by Transport Technology in the United Kingdom.

Permitted Contents:

Two types of baskets are designed for Unifetch:

1) Baskets with maximum capacity of 24 fuel elements: Irradiated BR-2 nuclear fuel elements, assembled from plates, consisting of an inner core of natural or enriched uranium alloyed with aluminum contained within an aluminum cladding.

Fuel core thickness	0.51 mm (0.02 in)
Maximum pre-irradiation mass of ^{235}U	405 g (14.1 oz)
Maximum mass per unit length of ^{235}U/assembly	5.495 g/cm (0.5 oz/in)
Maximum decay heat per fuel element	10.7 Watts
Maximum decay heat per package	260 Watts
Minimum fuel active length	737 mm (29 in)
Maximum fuel active cross section	5,384.56 mm^2 (8.35 in^2)
Cladding thickness	0.38 mm (0.01 in)
Maximum activity of package	45.4 kCi (1.68 PBq)
Minimum cooling time	90 days

2) Baskets with maximum capacity of 40 fuel elements: Irradiated MTR boxed type nuclear fuel elements, assembled from plates, consisting of an inner core of natural or enriched uranium alloyed with aluminum contained within an aluminum cladding.

Maximum mass of ^{235}U per element	170 g (6.7 in)
Maximum mass of ^{235}U in the shield	1,265 g (2.8 lbs)
Maximum decay heat per fuel element	11.5 Watts
Maximum decay heat per package	460 Watts
Minimum fuel active length	58.42 cm (23 in)
Maximum activity of package	123.3 kCi (4.56 PBq)
Minimum cooling time	90 days

GOSLAR

The Goslar cask is a double-walled right circular cylindrical steel container that uses lead shielding in the annulus between the inner containment and outer structural container. The Goslar-Behatler was previously used to transport boxed-type MTR elements with ^{235}U enrichment between 20 percent and 93 percent from several foreign research reactors to the United States.

Goslar was designed and fabricated by Transnuklear GmbH. It weighs approximately 10.9 metric tons (24,000 lb) and has inner cavity dimensions of 483 mm (19 in) diameter x 960 mm (37.8 in) tall. Exterior dimensions, including impact limiters, are 1,185 mm (46.4 in) diameter and 1,460 mm (57.4 in) height.

Permitted Contents:

Three different fuel configurations are authorized to be used with this cask. These accommodate various types and amounts of fuel:

1) A maximum of 13 irradiated MTR fuel elements (consisting of flat or curved fuel plates) with the following further specifications per fuel element:

Maximum initial enrichment	93 percent
Chemical form	U-Al alloy
Maximum initial mass of ^{235}U	320 g (11.1 oz)
Minimum cooling time	120 days
Thermal power	maximum 300 Watts
Maximum activity	89.2 kCi (3.3 PBq)
Thermal power	maximum 3,200 Watts per cask
Maximum activity	960 kCi (35.5 PBq) per cask

2) A maximum of 13 irradiated boxed-type MTR fuel elements, with the following further specifications per fuel element:

Maximum initial enrichment	45 percent
Maximum initial mass of ^{235}U	323 g (11.2 oz)
Minimum cooling time	120 days
Thermal power	maximum 300 Watts
Maximum activity	89.2 kCi (3.3 PBq)
Thermal power	maximum 3,200 Watts per cask
Maximum activity	960 kCi (35.5 PBq) per cask

3) A maximum of 13 irradiated MTR fuel elements with a total of 10.4 kg (22.9 lbs) of uranium enriched between 17 to 80 percent with a maximum of 1.755 kg (3.9 lbs) of ^{235}U, with the following further specifications per fuel element:

Maximum initial enrichment	80 percent
Maximum initial mass of ^{235}U	135 g (4.7 oz)
Minimum cooling time	200 days
Thermal power	maximum 1 Watt
Activity	maximum 300 Ci (.0111 PBq)

B.2.2.2 Ground/Intersite Transport

Table B-15 identifies the transportation casks for ground/intersite transport of foreign research reactor spent nuclear fuel. Each of these casks has a valid certificate for use in the United States. Although some of these transportation casks are not currently certified for the shipment of research reactor spent nuclear fuel similar to that from foreign research reactors, it is anticipated that all of the casks could be recertified to accept such material.

Table B-15 Transportation Casks for Ground Transport

Transportation Cask	*Certificate Number*	*DOE Experience*	*Country of Origin*
NLI-10/24	USA/9023/B( )F	No	United States
IF-300	USA/9001/B( )F	Yes	United States
BMI-1	USA/5957/B(U)F	Yes	United States
GE-2000	USA/9228/B(U)F	No	United States
TN-8	USA/9015/B( )	Yes	Germany
NLI-1/2	USA/9010/B( )F	Yes	United States
NAC-LWT	USA/9225/B(U)F	Yes	United States

Design information for ground transportation casks is summarized in Table B-16. Additional narrative summary information on each of theses casks is also provided below. Although no numbers are given for each cask capacity in terms of number of foreign research reactor spent nuclear fuel elements, it has been estimated that the space for each pressurized water reactor element (assembly) can accommodate 12 to 16 foreign research reactor spent nuclear fuel elements.

NLI-10/24

The Nuclear Assurance Corporation NLI-10/24 is a railcar transported stainless steel transportation cask. The cask is 519.4 cm (204.5 in) long, 234.8 cm (96 in) diameter, and weighs 72.5 metric tons (159,000 lb) empty. Radioactive shielding is provided by lead, water, depleted uranium, and a high temperature polymer. The cask is authorized to contain either 10 pressurized water reactor or 24 BWR irradiated uranium-oxide fuel assemblies.

Table B-16 Transportation Cask Design Characteristics for Ground Transport

Transportation Cask	*Empty Weight (metric tons)*	*Fuel Type*	*Number of Elements /Cask*	*Decay Heat Generation (kW)*	*Cooling Time (Days)*	*Cask Dimensions (mm)*
NLI-10/24[a]	77.5	PWR or BWR	10 PWR/ 24 BWR	70	150	H: 5,995 D: 2,440
IF-300[a]	43.1	PWR or BWR	7 PWR/ 17 BWR	11.7	120	H: 5,335 D: 1,625
BMI-1	9.9	MTR boxed-type	24	1.5	90	H: 1,864 D: 856
GE-2000	12.7	HFIR[b] Irradiated fuel	1	0.6	120	H: 3,340 D: 1,829
TN-8[a] (TN-9)[a]	16.3 (16.3)	PWR (BWR)	3 (7)	35.5 (24.4)	150 (150)	H: 5,740 D: 1,700
NLI-1/2	21	PWR or BWR	1 PWR/ 2 BWR	10.6/ 10.6	150/ 120	H: 4,953 D: 1,200
NAC-LWT[a]	23.2	PWR or BWR MTR	1 PWR/ 2 BWR 15	2.5/ 1.1 1	730 365	H: 5,080 D: 1,120

[a] *Currently does not have proper certification for foreign research reactor spent nuclear fuel use.*

[b] *High Flux Isotope Reactor fuel is similar to that of RHF fuel.*

PWR = Pressurized Water Reactor

BWR = Boiling Water Reactor

IF-300

The General Electric IF-300 is a stainless steel encased, depleted uranium transportation cask. The cask is 533.4 cm (210 in) long, 162.6 cm (64 in) in diameter, and weighs 43.1 metric ton (95,000 lb) empty. Radioactive shielding is provided by depleted uranium, stainless steel, and a water-ethylene glycol mixture. The cask is permitted to ship 7 pressurized water reactor or 17 boiling water reactor irradiated uranium-oxide fuel assemblies. The IF-300 transportation cask is illustrated in Figure B-11.

BMI-1

The BMI-1 cask is a truck transported, steel-encased, lead shielded transportation cask. The basic body is a right circular cylinder measuring 1.86 m (73.37 in) high and 0.85 m (33.37 in) in diameter. The cask weighs about 9.9 metric tons (21,860 lb) empty. The cask is permitted to ship 24 MTR boxed-type irradiated fuel assemblies. DOE, the authorized user of the BMI-1, lends it almost exclusively for the domestic shipment of research reactor fuel. As such, its design includes eight licensed basket and canister combinations, including one for TRIGA fuel with an initial enrichment up to 93 percent. These fuels are very similar to those used by the foreign research reactors. The BMI-1 cask is illustrated in Figure B-12.

GE-2000

The GE-2000 is a truck transported, stainless steel transportation cask. It is constructed from stainless steel shells and uses lead as a shielding material. The cask is 3.34 m (131.5 in) long, 1.8 m (72 in) in diameter, and weighs about 12.7 metric tons (28,000 lb) fully loaded. Current authorized contents include irradiated fuel rods and by-product, source, or special nuclear material. The GE-2000 cask is used primarily for domestic shipments of research reactor spent nuclear fuel. It is currently being certified for

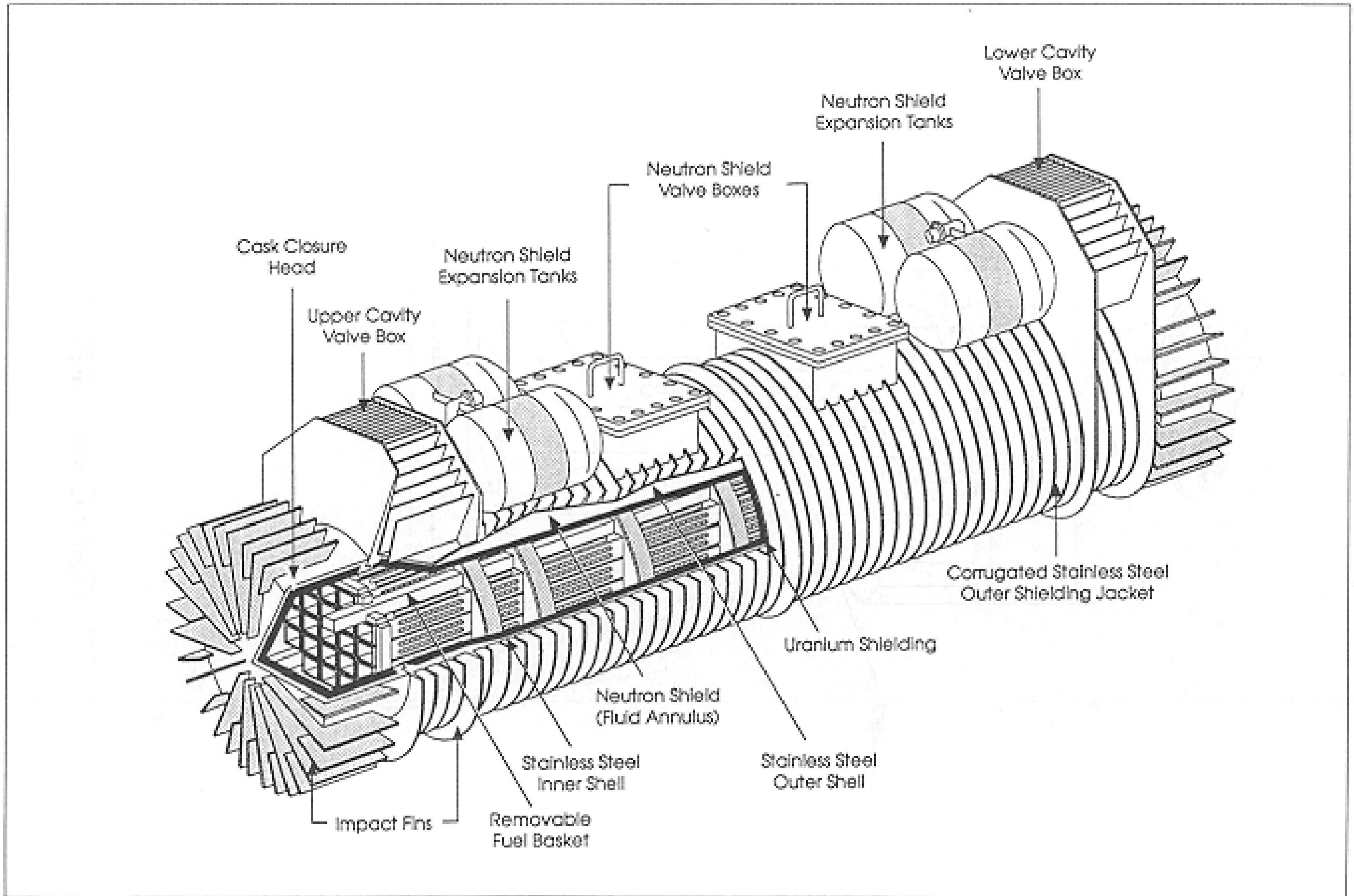


Figure B-11 IF-300 Shipping Cask

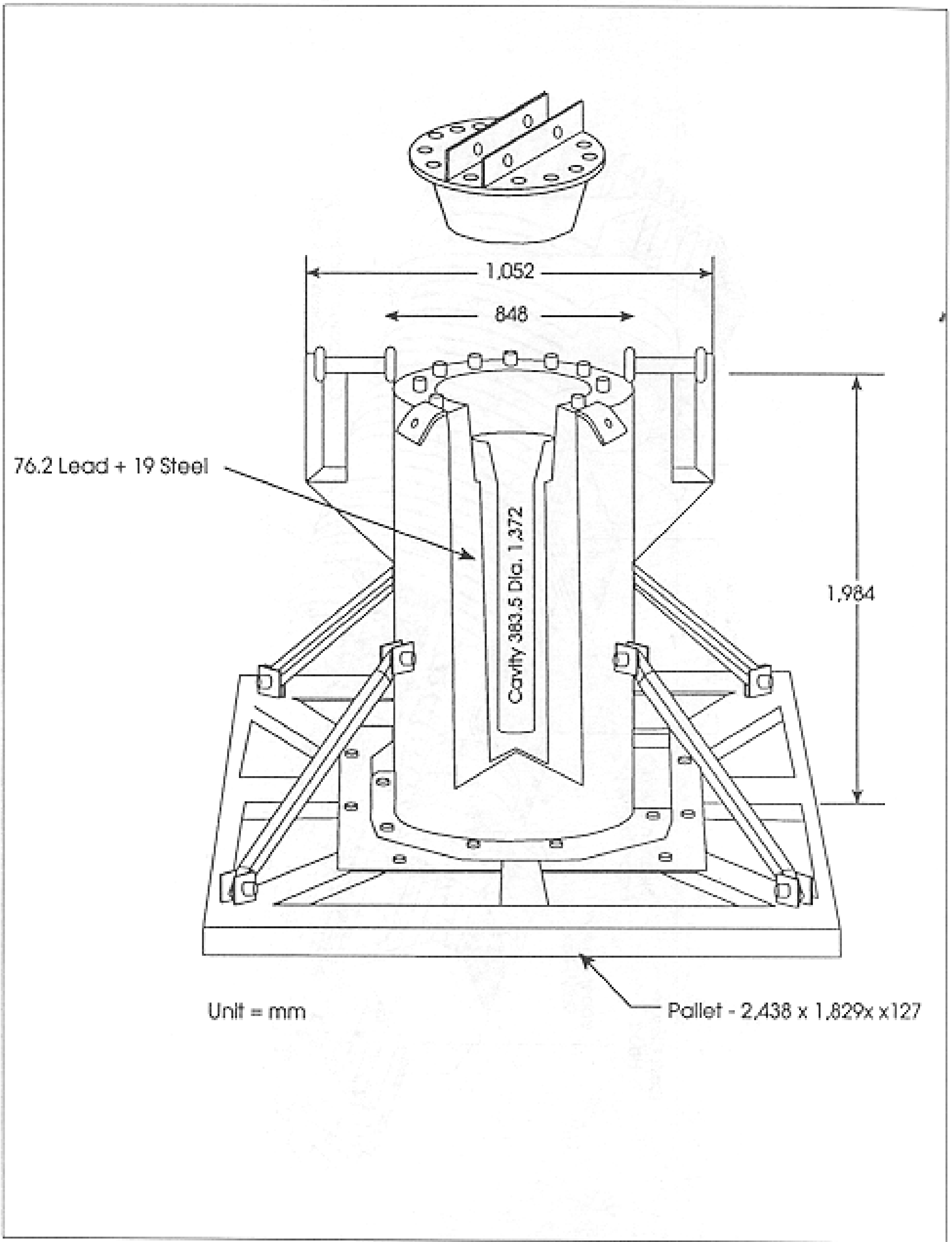


Figure B-12 BMI-1 Shipping Cask

use at the Oak Ridge National Laboratory for shipments of high flux isotope reactor fuel, which is almost similar in geometry to that used in RHF (see Section B.1.3) reactor but contains more ^{235}U fuel. The GE-2000 is illustrated in Figure B-13.

TN-8 (TN-9)

The Transnuclear TN-8 is a lead, steel, and resin shielded right cylinder, stainless steel transportation cask. The cask is 561.3 cm (221 in) long, 170 cm (67 in) in diameter, and weighs 16.3 metric tons (36,000 lb) empty. The TN-8 is permitted to ship three pressurized water reactor irradiated fuel assemblies. The TN-9 transportation cask is nearly identical to the TN-8, however, it is permitted to ship seven BWR irradiated fuel assemblies. These casks are classified as overweight truck casks in highway transport.

NLI-1/2

The Nuclear Assurance Corporation NLI-1/2 is a depleted uranium, water, and lead shielded transportation cask, encased in stainless steel. Shielding is provided by depleted uranium, lead, and a borated water-ethylene glycol mixture. The cask measures 495.3 cm (195 in) long, 120 cm (47.125 in) in diameter, and weighs 21 metric tons (49,250 lb) empty. It is permitted to ship either 1 pressurized water reactor or 2 boiling water reactor irradiated fuel assemblies. The NLI-1/2 is a legal weight truck cask that has been used at the Savannah River Site for the receipt of Taiwanese foreign research reactor spent nuclear fuel as recently as 1990. The NLI-1/2 is illustrated in Figure B-14.

NAC-LWT

The Nuclear Assurance Corporation NAC-LWT is a truck transported, steel-encased, lead shielded transportation cask. Radioactive shielding is provided by stainless steel and lead. The cask measures 508 cm (200 in) long, 165.1 cm (65 in) in diameter, and weighs 22.4 metric tons (51,200 lb) full. The cask is permitted to ship either one pressurized water reactor or two boiling water reactor irradiated fuel assemblies. This cask is also certified for the transport of Taiwanese foreign research reactor spent nuclear fuel. The NAC-LWT is nearly identical to the NLI-1/2.

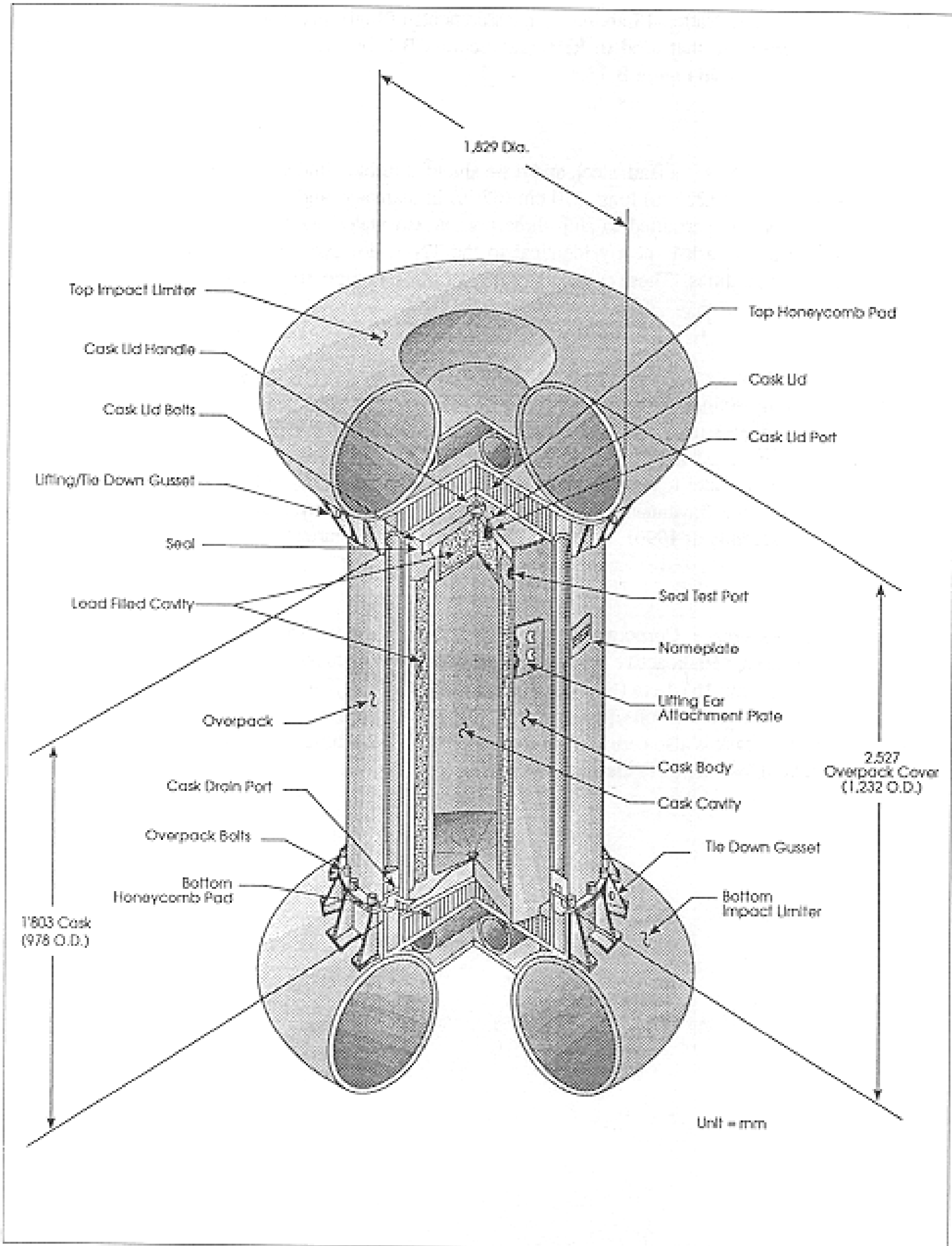


Figure B-13 GE-2000 Shipping Cask

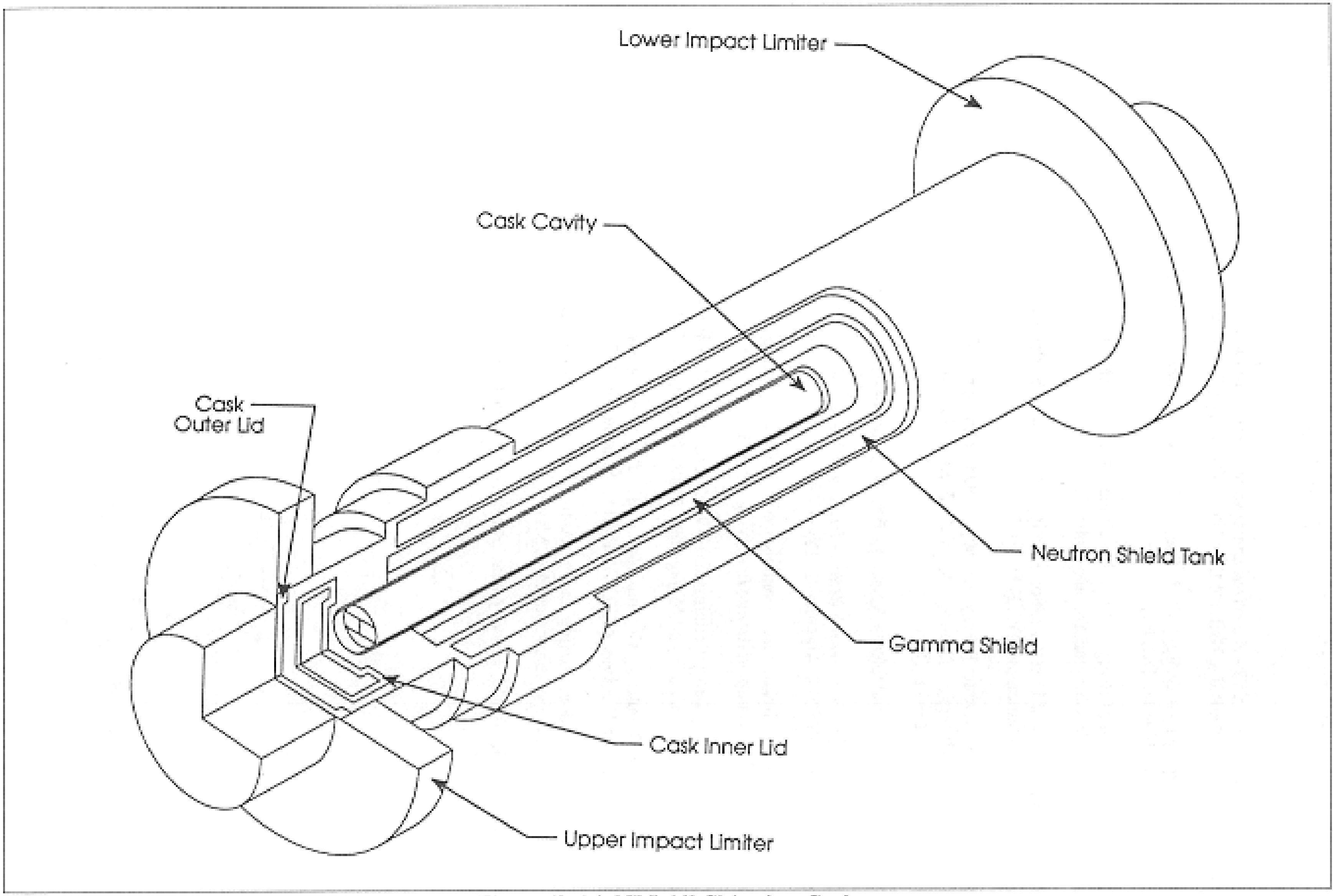


Figure B-14 NLI-1/2 Shipping Cask

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